



THE CANADIAN FISH CULTURIST

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THE DEPARTMENT OF FISHERIES OF CANADA



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Correspondence should be addressed to the DIRECTOR, INFORMATION AND CONSUMER SERVICE, DEPARTMENT OF FISHERIES, OTTAWA, CANADA.

Published under Authority
of

HON. H. J. ROBICHAUD, M.P.
Minister of Fisheries

Water Pollution and Fish Populations in the Province of Newfoundland and Labrador in 1964

by V. R. Taylor

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Note: This review is based on a paper prepared by Mr. Taylor for a Symposium on Pollution of Water, Air and Soil, sponsored by the Province of Newfoundland and Labrador. The meeting took place at St. John's on October 14, 1964, and was attended by an audience of specialists, administrators and laymen with a wide variety of interests.

Introduction

Fish populations in the province of Newfoundland and Labrador, like those of many other areas, are being subjected to increasing adverse pressure due to water pollution caused by industrial and domestic wastes disposal programs. As a consequence, many aquatic areas of the province are no longer in a pure and unsullied state. Because of the existing and potential effect of such conditions on fish populations, studies are being conducted by the Department of Fisheries of Canada to determine the seriousness of the situation from the fisheries point of view. Fresh-water areas are of particular concern, though marine areas are not immune to similar adverse effects.

Technically, pollution is the addition to natural water of any substance that changes its quality. From the point of view of fish life, it is the addition of anything that lessens its ability to support normal fish populations; and although this review is concerned only with fish, it might be pointed out that a river that is so polluted that it can no longer support its normal fish population, has implications far more serious than the fate of fish. As one author (Turing, 1952) has said "What do a few fish matter Actually, they matter very much, not because people who want to catch them cannot do so, but because their absence means a very sick river Water which is not fit for fish habitation is not fit for human needs either"

Because of the relatively confined nature of freshwaters, and the many demands upon them, pollution problems are usually more critical in these areas than they are in tidal waters, though each situation depends on many things: including the nature of the pollutant, the fish population involved, the area in question, and a host of other factors.

The Situation in 1964

For convenience sake, pollution problems in the province of Newfoundland may be grouped into a few classifications. That which follows is based mainly on the source of the pollutant, the most important ones in Newfoundland and Labrador being: (i) wastes from the mining industry, (ii) wastes from pulp and

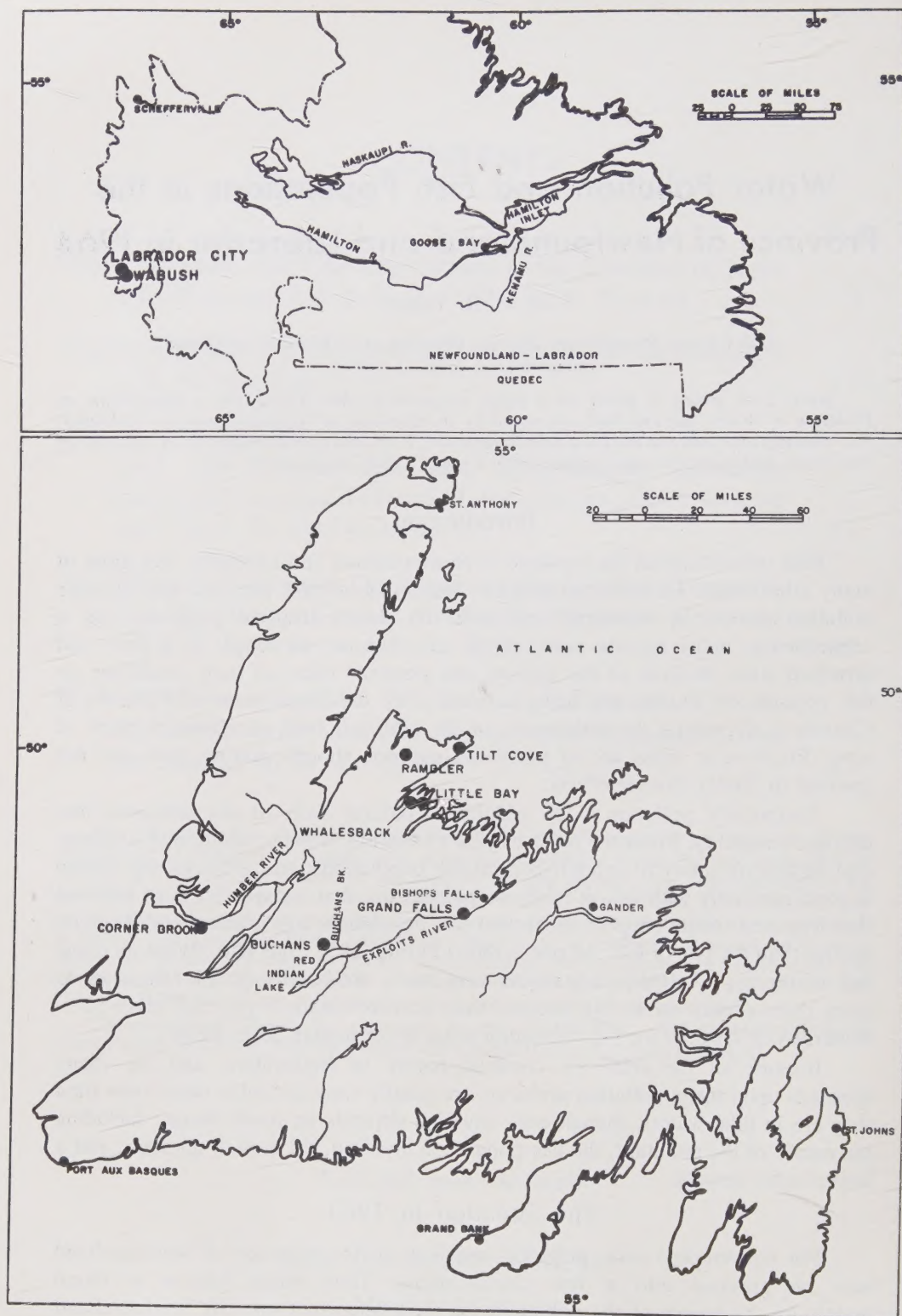


FIGURE 1. Map of Newfoundland and Labrador showing areas mentioned in text.

paper manufacture, (iii) domestic sewage disposal, and (iv) miscellaneous sources of pollution. Each is briefly discussed in the following review. Figure 1 indicates the location of some of the more important existing or potential pollution areas in the province.

Wastes from the Mining Industry

Although some attempts at mining began in the province as early as the last quarter of the eighteenth century, the industry did not become firmly established until 1892 when exploitation began of the iron ore deposits at Bell Island and, although other deposits were brought into production in the intervening period, the years since the end of World War II have seen a marked increase in the tempo of mining activity in the province.

In the area of Labrador, two very large iron ore operations have begun, or will begin, large scale production very shortly. Each of these operations produces a "beneficiated" product from the treatment of some 15,000,000 to 20,000,000 tons of raw ore annually. This results in about 60 percent of the mined material being discarded as wastes, the higher grade materials (about 40 percent) being shipped to market.

These millions of tons of wastes (called "tailings") are largely finely divided low grade material that has been separated from the richer ores, and which must be disposed of in some way. When spilled into water areas, which is where most of them finally end up, these wastes may be carried for long distances. The heavier particles settle out quite rapidly. The more finely divided material can travel great distances, and is kept in suspension for long periods by the action of wind and currents (Figure 2). The main effects of these in excessive quantities are: (i) to destroy spawning areas by siltation, (ii) to smother plant and invertebrate growth on the bottom, (iii) by reduction of light penetration, decrease general food production, and (iv) by effects on certain tissues, especially respiratory, directly decrease the ability of fish to survive.

The problem of finding suitable areas for disposal, without harm to fish populations, of the millions of tons of tailings involved is not easily solved. In the case of one of the operations in the Labrador area, a lake of 3,000 acres in extent will be isolated from surrounding waters and used, in effect, as a large settling basin. In this case it is expected that tailings will eventually fill the lake well above its present water level. Even though this lake will be removed from the realm of fish production, the scheme will have the advantage of preventing indiscriminate spreading of tailings to connecting waters.

In the case of the second operation, a large dyked area is being enclosed within an even larger lake. This, when completed, should form "a lake within a lake" and provide some reduction of spread of tailings to adjoining waters. However, because of the time factor in constructing the dyke, and because it is being constructed of tailings, it has not yet contributed appreciably to containing fines from the disposal operation in question.

On the island of Newfoundland the situation is somewhat different. Only one iron ore mine is in production, and wastes from its beneficiation plant are discharged directly to the sea. Here, except in a very limited area, it seems unlikely that



FIGURE 2. *A lake polluted by mine concentrator wastes. A demarcation between relatively clean outside water and water closer to shore discoloured by "fines" can be seen at lower left.*

substantial effect on fish populations occurs, since these wastes are rapidly diluted and dispersed. However, there have been complaints to the effect that fishing gear and equipment located many miles away are fouled, and their efficiency reduced, by fines from this operation.

The primary effects of the iron ore operations discussed are those due to their physical actions—turbidity, smothering, gill irritation, etc. This means that the wastes themselves are practically inert. That is, the physical effect is predominant, and there is little known toxic effect due to chemicals in solution. Those to follow have a dual chemical and physical effect. These are the operations concerned with the extraction of the "heavy" metals, copper, lead, and zinc. A number of these are in production, and others will become so in the near future. Because of the harmful effects of such mine wastes, at very low concentrations, on fish populations in receiving waters, the federal Department of Mines and Technical Surveys is also initiating studies with a view toward determining ways and means by which the situation may be alleviated.

Four "heavy" metal mines are now in operation and two additional are expected to begin production in 1965. Of the six mines, five produce, or will

produce, mainly copper. One (at Buchans) also produces lead and zinc. Two of these mines are located on tidewater and the other four in inland areas. Wastes from all are of concern to the Department of Fisheries because of their possible effect on fish populations if proper precautions are not taken.

Tailings spilled from ore concentrators located at each of these sites have much the same physical effects as those from the iron ore operations just described, i.e. smothering, turbidity, and mechanical irritation. Chemically, and more difficult to control, these tailings also carry lead, copper, and zinc in solution. In addition to their primary physical effects, the solid tailings are also a continuing source of supply of copper and zinc ions to the receiving waters. In most local waters lead is fairly rapidly precipitated out and is a lesser problem.

Zinc and copper in solution are toxic to fish life at very low concentrations. In similar waters elsewhere, 0.60 ppm of zinc, or 0.048 ppm of copper, are the Incipient Lethal Levels (ILL)—the concentrations at which the organism can no longer survive for an indefinite period of time (Fry, 1947; Sprague, 1964). With this value known, other concentrations of these substances may be expressed as multiples of the ILL. Thus it has been shown that concentrations of dissolved zinc or copper equal to 40 percent of their ILL is the level at which, under natural conditions, Atlantic salmon begin to be adversely affected. This concentration may be expressed as 0.4ILL (Sprague, *et al.*, 1964).

In the freshwater environment, wastes from the mine at Buchans are a source of concern. This mine, which began operation in 1927, processes raw ores to produce lead, zinc, and copper concentrates. Some 360,000 tons of ore are processed each year, of which some 260,000 tons are disposed of as tailings to Buchans Brook and thence to Red Indian Lake and downstream areas of the Exploits River.

Until a few years ago when this Department began surveys, no investigation of the effect on receiving waters of this disposal operation had been carried out. Recent studies have shown three water areas to be affected. These are (i) the approximately 5 miles of Buchans Brook below effluent entry, (ii) Red Indian Lake, and (iii) the Exploits River below Red Indian Lake.

Below the point of entry of concentrator wastes into Buchans Brook, a stream draining an estimated 100 square miles of watershed, no life is known to survive due to (a) the physical effects of large amounts of silt in these waters, and (b) lethal levels of dissolved zinc and copper. Zinc concentrations in this brook, in terms of Incipient Lethal Level, run at least as high as 100ILL, or some 200 times that recommended as a maximum for young salmon. Within a radius of several hundred yards from where Buchans Brook enters Red Indian Lake, concentrations are still at a level of 10ILL, or 20 times the recommended level.

Combined concentrations (Sprague, 1964a) of zinc and copper in the main body of the lake, particularly its northern half, range from 0.3ILL to 1.0ILL, and several miles downstream on the Exploits River combined zinc and copper levels ranging from 0.1 to 0.8ILL have been determined by regular sampling operations.

The situation in these waters may be briefly described by saying that (i) Buchans Brook below the point of entry of these wastes is grossly polluted by physical and chemical waste products, (ii) to a lesser degree, but still serious, the

same may be said for an area of Red Indian Lake within a radius of at least one-half mile from the mouth of Buchans Brook, (iii) the lake bottom has large deposits, in the central one-third in particular, of silt that must severely inhibit the growth of bottom fauna, and (iv) dissolved zinc and copper concentrations in the lower river, though at lesser levels than in the lake, are still present in amounts such as to cause concern about their effect on migratory salmon populations. Discussions with the company involved are underway to try to find an acceptable method of waste treatment, and disposal, that will reduce metal pollution in these waters to levels tolerable by fish life.

Two copper mines in insular Newfoundland are located at tidewater. Both are on the Baie Verte Peninsula, one being located at Tilt Cove and the other at Little Bay, a few miles from Springdale.

The mine at Tilt Cove spills some 7,000 tons of liquid wastes, and about 2,000 tons of solid wastes each day. These discharge directly to tidal water from the concentrator. Because of the very large dilution available in the surrounding sea, chemicals in solution have not been traced more than a few hundred yards or so from the effluent pipe. Consequently, from this point of view, little harm is believed done to fish populations except in the immediate vicinity of the discharge. Fines from solid tailings are, however, distributed a considerable distance by the action of wind and tide.

At the Little Bay mine, near Springdale, about 900 tons of solid tailings, and an estimated 3,000 tons of liquid tailings are spilled daily to a small arm of the sea called Shoal Arm. This arm, which is some 50 acres in extent, formerly opened to the sea by a narrow mouth and acted as a partial settling basin. Nonetheless, turbid water was often carried by wind and tide to outside waters. The company, on request, constructed a low dam across the mouth of Shoal Arm which confined the spread of fines to the arm itself.

An additional copper mine has recently begun production in the Baie Verte Peninsula area and another will become operative soon. Both of these propose to discharge concentrator wastes into freshwaters, and discussions have been held to find acceptable ways to reduce the effects of these liquid and solid tailings on fish and other aquatic life. Some success has been achieved in confining solid wastes to limited areas in both cases but the problem of chemicals in solution, especially copper and zinc, is more difficult to solve. No large runs of anadromous species are involved in either of these operations but the Department takes the attitude that fish populations, even if not fully exploited at present, should not be unnecessarily destroyed.

Another copper deposit, located near Gull Pond, a major lake on South Brook, Halls Bay, will be brought into production in 1966. A concentrator for copper ore will also be a feature of this operation. In this case it seems likely, unless very careful precautions are taken, that substantial physical and chemical pollution of the downstream areas of South Brook may result.

The stream involved, South Brook, is one of three good sea-run salmon and trout streams flowing into Halls Bay at the base of the Baie Verte Peninsula. These streams provide the best recreational fishery, and almost the only substantial sport fishery for salmon, between the Exploits and Humber Rivers situated some fifty

miles on either side of Halls Bay. In addition, each river also contributes substantially to the commercial salmon fishery in the area. Discussions were initiated some time ago to attempt to find a satisfactory solution to the problem of wastes from this mining development.

The foregoing has concerned itself with wastes disposal from iron ore mines and "heavy" metal mines. Other mines are in operation in the province but these are not known to contribute significantly to the water pollution problem.

Wastes from Pulp and Paper Manufacture

Two large newsprint mills are established on the island of Newfoundland. One is situated at Corner Brook, on the West Coast, and the other at Grand Falls, on the Exploits River. Annual production at the Corner Brook mill is in the order of 320,000 tons of newsprint and 30,000 tons of sulfite pulp; at Grand Falls it is about 220,000 tons of newsprint and some 7,000 tons of sulfite pulp. In both cases the sulfite figures quoted are for export pulp and are additional to sulfite pulp used in the production of newsprint.

At both locations newsprint is produced by a groundwood-sulfite pulp combination in the approximate proportions of 80:20 respectively. Much larger quantities of sulfite pulp are produced for newsprint production, therefore, than is produced for export. Wastes from sulfite pulp production, by the calcium process used in both mills, have a very high oxygen demand and figure prominently in pollution due to such operations.

A survey of the receiving waters for the effluent from both these mills was conducted in 1942 (Vavasour and Blair, 1955). No significant pollution, such as would endanger fish populations, was reported as a result of that survey. Since that time, wastes from both mills have increased as a result of stepped-up production (Figure 3). At the same time, domestic wastes from adjoining towns have also increased.

Wastes from the mill at Corner Brook empty directly into Humber Arm, Bay of Islands, about two miles from the mouth of the Humber River, probably the single most productive salmon river on the island. The location of waste outfalls away from the river mouth, and the dilution effect of the waters of Humber Arm seem, so far, to have nullified the effects of these wastes on salmon escapements to the Humber River. Because of these factors no major pollution problem is known to exist in the area. It must be emphasized, however, that the area has not been examined in detail since the 1942 survey was conducted.

The situation due to wastes disposal from the mill at Grand Falls differs in many ways from that just discussed. The most obvious difference is that this mill is located some ten miles upstream on a river. All mill (and town) wastes are discharged directly to this river which is a migratory path for anadromous salmon and trout.

Because of the Department's concern for anadromous and freshwater fish, and because the Exploits is the largest river on the island and has much potential for salmon development (less than 20 percent of its watershed being utilized by salmon due, mainly, to natural obstructions), sampling and observation was begun



FIGURE 3. *The area of white water close to the river bank in the centre foreground is due to wastes from a pulp and paper mill, the outfalls of which are located at extreme right. Light water areas on the opposite side of the river are due to fast water in a tributary which joins the main river at that point.*

some years ago to measure the effect on fish populations of these wastes. As a result, it can be said that the situation in the river below Grand Falls gives cause for concern due to river conditions during migration periods.

This discussion of the effects of mill wastes to the Exploits River at Grand Falls concerns itself mainly with Sulfite Waste Liquor (SWL). The deleterious effects of this waste predominate over those of all other wastes combined (e.g. the oxygen demand from the wastes required to produce one ton of sulfite pulp is in the order of 600 pounds, that from one ton of groundwood pulp about 10 - 20 pounds).

SWL exerts two main effects on fish populations. These are (i) a toxic effect on the fish themselves, and (ii) a reduction of dissolved oxygen in the receiving waters which may make them unsuitable for fish life. In evaluating toxicity, it must be borne in mind that in the experiments to determine critical levels of SWL to which reference is made (Holland, 1960) dissolved oxygen was artificially maintained, whereas in a natural situation the two would operate together. Considering toxicity alone, therefore, probably provides an over optimistic view of the situation prevailing.

Average flow in the Exploits River ranges from a high of about 25,000 cfs to a low of around 2,000 cfs. In the area below Grand Falls, flow is seldom less than 5,000 cfs since the requirement of the powerhouse at the falls is of that order and

additional water is provided from storage during low flow periods. These low flow periods usually occur during the months of July and August, the time of Atlantic salmon upstream migration to their spawning grounds. This flow of 5,000 cfs is the equivalent of about 135,000,000 U.S. gal. per hr. The flow of sulfite waste liquor from sulfite production is approximately 24,000 U.S. gal. per hr.

The SWL experiments referred to in the foregoing were based on a 10 percent total solids content. SWL spilled at Grand Falls has a total solids content of 11-14 percent. It is assumed in the following that it is adequately described by the average of this range, namely 12.5 percent total solids.

To compare the effect of SWL at Grand Falls, therefore, with the experimental data referred to, it is necessary to express SWL at Grand Falls in terms of 10 percent total solids. The hourly SWL discharge becomes, by this method, about 30,000 U.S. gal per hr. of 10 percent SWL. Using this figure, the flow of SWL into 135,000,000 U.S. gal. per hr. of river water gives a concentration of about 220 ppm SWL at river flow of 5,000 cfs.

The same experiments showed that at a SWL concentration of 500 ppm a dangerous situation for young salmon was being entered upon. In these experiments, as noted earlier, dissolved oxygen level was artificially maintained, whereas in the natural situation it would be lowered by the concomitant oxygen demand of SWL, so that the situation would be less favourable to fish.

The detailed implications for Exploits River salmon and trout populations of SWL in the concentration shown cannot be stated for the following reasons:

- (a) Atlantic salmon may be slightly more or less susceptible to SWL than the Pacific species tested.
- (b) Experiments were conducted on young fish. Adults may be more or less tolerant, but other work does not suggest that this would provide much greater long term resistance to the effects of SWL.
- (c) SWL in the river is not uniformly distributed for several hundred yards below the outfalls. This means that in some areas concentrations are probably lethal, while in others they may be harmless.
- (d) Sampling data is not sufficiently precise to accurately chart SWL concentrations in affected areas of the river.

It may be stated with confidence, however, that during the adult migration period, which usually occurs during flow periods of 5,000 cfs (perhaps less, at times, due to operations at the powerhouse) there is real cause for concern. During the period of smolt migration, river flows (May-June) are usually well above summer low flow levels, so that SWL concentrations, in most years, should not reach dangerous levels at this time. Since most smolts now originate well below Grand Falls it is probable that, for most of them, the worst zones of SWL pollution do not have to be traversed. There are, however, serious implications for development (for salmon production) of the area above Grand Falls since both adults and smolts from this area would have to pass through the areas of worst SWL concentrations.

Experiments have also been conducted to determine whether migratory salmon (adult or young) would deliberately avoid areas of SWL pollution, if cleaner water were available, and thus escape the worst effects of traversing zones

of serious SWL pollution. These experiments (Holland, G.A. *et al.*, 1960) indicated that, for SWL concentrations from 300 to 1,000 ppm, no well established aversion could be demonstrated.

As noted earlier, SWL has, in addition to its direct toxic effects, a large demand for dissolved oxygen. Obviously, the less water available to satisfy this oxygen demand, the more likely that depletion will occur. It is assumed, in the following, that minimum flows in the Exploits River are 5,000 cfs, and that salmon require not less than 5 ppm dissolved oxygen to enable them to survive and carry out normal functions.

At a low flow of 5,000 cfs in the Exploits below Grand Falls, and an average dissolved oxygen level of around 8 ppm, about 100 tons of oxygen are available on a daily basis in the area of the outfalls. The oxygen demand of the waste products from one ton of sulfite pulp production is estimated to be some 600 pounds (Beak, 1962), though some authors (Eldridge, 1960) report it to be as high as 700. Based on an average production of some 250 tons of sulfite pulp per day at Grand Falls, there is an approximate oxygen demand of some 150,000 pounds, or about 75 tons, by these wastes in that area. From the point of view, therefore, of the oxygen demand of SWL at low flows, it is obvious that a good situation does not exist since these wastes require some 75 percent of the dissolved oxygen available. It seems here that "the day is saved", at least partially, by the fact that wastes are not evenly distributed in the river, so that while some areas are almost devoid of dissolved oxygen, others retain a sufficiently high level to enable fish to migrate through. Actual oxygen determinations have shown some areas of the river to be below 2 ppm at times. It has also been noted that, while upstream of the polluted area fish (resident trout) are fairly plentiful, in and below this area they are, for practical purposes, non-existent—as are juvenile salmon. This is as might be expected under such conditions.

It is also important to note that, in the Exploits River below Grand Falls, the effects of SWL due to toxicity and oxygen depletion are further compounded by the presence of zinc and copper in solution (from mine wastes disposal) and, a few hundred yards below the mill outfalls, by domestic sewage from the twin towns of Grand Falls and Windsor. Mine wastes were discussed earlier, the effect of domestic sewage is reviewed in the following paragraphs.

Domestic Sewage Disposal

There are not many large communities in the province of Newfoundland and Labrador and, with a few exceptions, they are situated near tidal waters. Thus pollution due to domestic sewage disposal has not been as widespread as elsewhere. There is, however, a problem on the Exploits due to domestic sewage disposal from Grand Falls and Windsor. This probably would not be too important, from the fisheries point of view, were it not operating in conjunction with the effects of SWL from the Grand Falls mill. On the basis of a population in the order of 10,000 people, the BOD of the sewage wastes from these towns should be in the order of about 1 ton per day. It was noted earlier that oxygen available in the river at a flow of 5,000 cfs would be about 100 tons per day. This demand

should thus be easily satisfied with no hint of depletion. Conditions in the area of sewer outfalls, however, are not normal since they are located only about one-half mile below outfalls for SWL.

Measurements in 1961 (Figure 4) showed that, a few hundred yards below the point of SWL entry (Station No. 2), dissolved oxygen was reduced to an average of 65 percent saturation (range 39-85%, 3.4-7.9 ppm). Just below this area (Station No. 3) there is a small rapids, and some recovery of dissolved oxygen occurs—to 75 percent saturation (3.0-12ppm). This is temporary, since it seems that the SWL has not been totally oxidized in the short stretch of river in question. A few hundred yards below this station (at Station No. 4), and below two town sewer outfalls, dissolved oxygen levels drop even further than at Station No. 2. This is attributed to the fact that (i) the continuing oxidation of sewage wastes, with normal oxygen supply, has over balanced the additional dissolved oxygen provided at the small rapids below Station No. 2, and (ii) nutrient salts in the sewage have accelerated the SWL oxidation rate. At the next sampling station (Station No. 5), which is below the entry of all mill wastes and domestic sewage, dissolved oxygen values drop to an average of 56 percent saturation (range 18-92%) or 5.6 ppm (range 1.7-9.7 ppm). Approximately nine miles farther downstream (Station No. 6) recovery of dissolved oxygen levels becomes apparent. Even at this point, however, normal values had not been fully restored.

As far as domestic sewage in the Exploits River is concerned, it can be said, therefore, that the volume is insufficient to cause any lack of dissolved oxygen. However, entry is in an area already polluted by SWL, and the effect of nutrient salts in the sewage is such as to accelerate oxidation of SWL and thus worsen a situation which was marginal prior to that time.

Miscellaneous Sources of Pollution

In addition to the major sources of pollution outlined in the foregoing, numerous isolated instances occur regularly. These relate mainly to such things as (i) gravel washing in or near salmon and trout streams to provide railway track ballast or highway construction materials, (ii) operation of sawmills, particularly in relation to sawdust disposal, (iii) use of insecticides, usually in more northern areas, for biting insect control, and (iv) small domestic sewage disposal problems, cesspool drainage and such like. These are handled on an *ad hoc* basis, and can usually be resolved without permanent harm being done to fish populations concerned.

Summary

From the foregoing it must be concluded that the province of Newfoundland and Labrador is no longer the pollution free area that it has sometimes been considered. Although fish populations and water pollution have been the theme of this report, it seems that the situation in some areas is such that unless reasonable foresight is exercised, and proper precautionary measures taken, the foreseeable future may see not only valuable fish stocks threatened, but perhaps other water resource uses also being unnecessarily jeopardized.

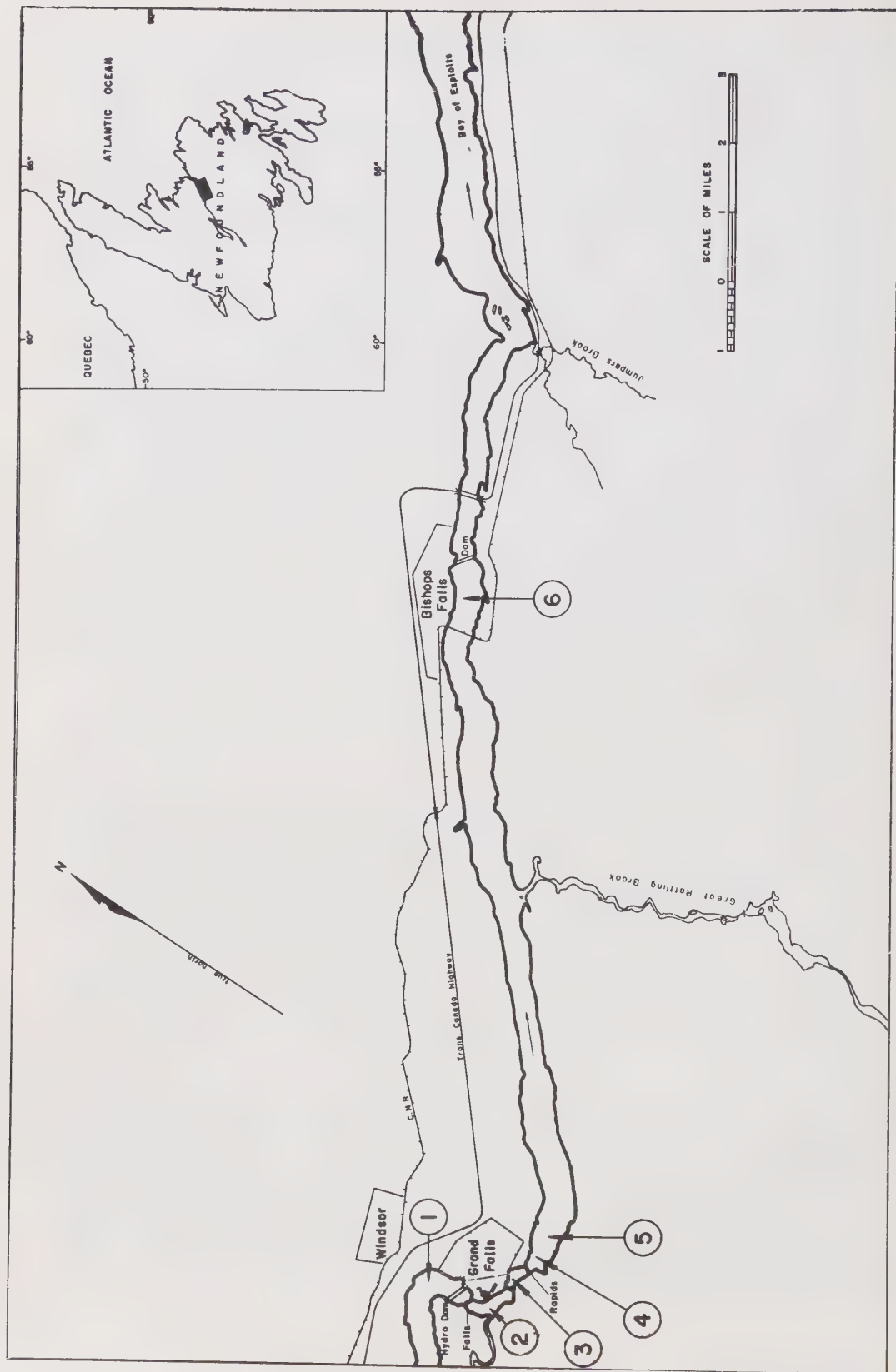


FIGURE 4. Water sampling stations on the lower Exploits River between Grand Falls and Bishop's Falls.

Acknowledgments

Results of sampling and analysis of Exploits River and Red Indian Lake waters used in the foregoing review are from Project Reports, compiled for Departmental use, by Biologist L. J. Cowley who conducted these investigations under the general direction of the writer. These reports are on file in the St. John's office of the Department of Fisheries of Canada. The writer's indebtedness to this work, and other information supplied by Mr. Cowley, is acknowledged. The author would also express his thanks to the several individuals who were kind enough to review the original manuscript and make suggestions for its improvement.

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Fisheries Problems Associated With Hydroelectric Development*

by

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Commercial fishing for salmon, and the processing of the product for domestic and foreign markets, is one of British Columbia's leading industries, providing full-time or seasonal employment for more than 15,000 persons. Countless thousands of others, not engaged in the fishing industry, owe substantial portions of their income to expenditures incurred by anglers, many of whom come from thousands of miles away just to land one of these prized fish on sport tackle. Yet, as important as salmon are to the provincial economy, and as a recreational resource, their continuing existence is being threatened as never before.

Until about a century ago the relative abundance of the salmon stocks depended solely on their ability to withstand the detrimental effects of such natural phenomena as droughts, floods, obstructions, predators and disease. Today these natural enemies are as prominent as ever, but they are no longer the only factors limiting salmon abundance; and on some streams they are now of relatively minor importance when compared with the hazards created by industrial developments which divert, disrupt, pollute, or otherwise interfere with the salmon's natural environment.

With the possible exception of pollution, hydro-electric power developments represent the most serious industrial threat to the salmon stocks. In British Columbia, as elsewhere, the post-war industrial expansion has been accompanied by an ever-increasing demand for electrical power, and this, in turn, has stimulated the hydroelectric industry's interest in many of the province's good salmon-producing rivers. There are, however, certain laws in force in Canada which require that such industries assume responsibility for fisheries protective measures made necessary by their undertakings.

Accordingly, the Department of Fisheries, which is charged with responsibility for the salmon stocks, collaborates with the sponsors of the individual projects in an attempt to develop solutions to all foreseeable fisheries problems. In some instances, this co-operative approach has met with success, whereas in others the problems have been so complex that solutions were not possible in the light of available knowledge.

*A paper presented to the Annual General Meeting of the Engineering Institute of Canada, Banff, Alberta, May 1964. Reprinted from the Engineering Journal.

This paper, which discusses briefly the most common problems associated with the maintenance of salmon stocks at hydroelectric developments, is intended to give the reader some insight into the scope and complexity of these problems, and the difficulties encountered in attempting to develop economic solutions. A brief description of the life cycle of Pacific salmon is included as this is fundamental to an understanding of the basic problems.

Pacific Salmon—Life Cycle

Pacific salmon, of which there are five species native to British Columbia, are born in fresh water from whence, at varying ages depending upon their species, they migrate to sea where they remain for at least one year. Growth during this period of marine residence is rapid, and as maturity approaches, they return to the stream or lake of their origin to spawn, and shortly thereafter they die.

Salmon en route to the spawning grounds cease to feed early in the migration, as their digestive organs virtually disappear to make room for the gonads, which develop to fill almost the entire body cavity by the time of the spawning act. As this process is not reversible all Pacific salmon die soon after spawning. Moreover, since there is no food intake during this migration the fish must draw upon the energies stored within their bodies to complete their journey and its fundamental purpose. As this stored energy is barely sufficient to fulfill the requirements there are few reserves on which the fish can draw to cope with abnormal situations calling for unusual or excessive expenditures of energy. Time is therefore of the essence because delays of even a few days can exhaust the energy reserves before their mission is accomplished.

Spawning occurs in the late summer or fall. The specific site is chosen by the female, and she is very selective with regard to such characteristics as depth, velocity, turbulence, gravel composition, etc. A deficiency in any of these properties may render an area unsuitable for spawning, and this accounts for the fact that on most streams only a very small proportion of the total available stream bed is utilized for this purpose.

The spawning act consists of the female scooping out a depression in the gravel of the stream bed, into which she deposits several thousand eggs which are fertilized simultaneously by the male. The nest is then back-filled with gravel to form a protective covering for the eggs while they incubate during the winter.

The young emerge from the gravel, as free-swimming fish, in the following spring, the exact time being determined by the temperature of the water during the incubation period—early, if the water has been relatively warm; and late, if it has been cold. Upon emergence from the gravel, chum and pink salmon migrate directly to sea; coho rear in the river or lake for at least one year; chinook (spring) may do either; and sockeye invariably migrate to a lake, where they reside for at least one year before proceeding to sea.

At a specific time in their life cycle juvenile salmon move seaward in mass migrations usually of several weeks' duration, which occur in the spring and early summer. At this stage they are still weak swimmers, and they progress only at approximately the rate of the river current. While the motivational instinct which initiates these mass migrations so abruptly is not clearly understood, it may be

related to rising water temperatures, increasing river discharges, or other factors associated with the advent of spring; or it may be tied closely to physiological changes taking place within the fish to prepare them for life in a salt water environment.

The Problems Posed by Hydroelectric Developments

The individual problems will be discussed in the order in which they might be expected to occur as the adults progress upstream, and as the juveniles proceed downstream.

Effects of Altered Discharge Patterns on the Adults

The flow regulation effected by most hydro developments during the spawning migrations usually creates flow patterns which differ from those occurring naturally, and these changes can interfere with the progress of the migrations.

While augmented flows normally are of little consequence, substantial reductions in discharge during the spawning migrations can be a serious matter. For instance, physical obstructions (falls, rapids, and shallows), which delay or block the migrants, might develop at locations where formerly there were none; or the water levels might be too low to induce the fish to continue. Flow reductions can therefore produce delays, the severity of which depends upon local conditions and the degree of flow regulation exercised at the plant.

Peaking plants which operate for only a few hours each day can be particularly troublesome from the fisheries viewpoint because of the widely-varying, rapidly-fluctuating water levels they produce downstream. Sudden changes in discharge can cause a cessation of migration while the fish await the return of stabilized conditions. Moreover, since salmon hold closely to the river margins during migrations, sudden reductions in flow, as might be expected below a peaking plant, can cause them to become stranded in isolated pockets when the water recedes.

Diversion-type hydro projects also present difficult problems, because they constitute a dual attraction for migrating salmon—some being drawn to the powerhouse tailrace, while the remainder follow the historic migration route. If substantial numbers are expected at the powerhouse some means must be provided for returning them to their natural stream; and, of course, adequate flows must be maintained in the natural stream to provide suitable conditions not only for these fish, but also for those which have followed the traditional migration route. While solutions such as this appear quite simple, their implementation usually is not, because the cost of the fish-protective works and the value of the power lost as a result of water releases to the river below the diversion works reportedly is often uneconomic from the power viewpoint.

Reductions in discharge frequently are accompanied by rising water temperatures, and while a rise of only a few degrees in some streams may not be a serious matter in so far as salmon are concerned, on others it could produce lethal conditions, since salmon are cold-blooded animals which cannot withstand sustained temperatures in excess of the range to which each race has become genetically adapted. Moreover, their rate of energy expenditure and the incidence of parasitism and disease increase sharply with rising water temperatures, so it is extremely important that normal conditions be maintained.

Altered flow patterns often present an additional problem for those salmon which spawn below the hydro development, since even moderate curtailment of normal flows can sometimes substantially reduce the area of the spawning grounds. Furthermore, the maintenance of normal or near-normal flows during the spawning period is not enough by itself—adequate flows must be maintained on the spawning grounds during the incubation period as well; otherwise deposited spawn will die of dehydration and suffocation.

While there undoubtedly is a minimum to which the natural flows can be reduced without harming the salmon stocks, local conditions vary so much with each stream that the only way of ensuring that altered flow patterns will not be detrimental is to provide continuous flows of approximately the same magnitude as those which occur in nature during the same period.

Attracting Adults from the Tailrace

Since salmon arriving at the toe of a hydro development must be able to ascend to the headpond without delay, the entrances to the fish-passage facilities must be positioned so that they are easily located by the fish, and they must be attractive to them.

While water temperatures normally are of no particular significance in so far as the entrances are concerned, salmon may be reluctant to enter facilities in which the water is considerably warmer than the tailrace—a situation which might occur at high-head plants where the turbines draw cold water from the head-pond via deeply-submerged intakes, while the fish facilities are supplied from the comparatively warm surface layers. Such problems are rather unusual, however, and attraction normally depends only on location and discharge.

Selection of the entrance locations is complicated by the fact that the fish facilities must be operable as soon as, or probably before the plant comes on line, and there is therefore no opportunity beforehand to observe fish behaviour under prototype conditions. Accordingly, the designer must rely on his experience and judgment, some speculation, and, where possible, hydraulic model studies.

Entrance outflows always are small in comparison to the plant flows and there is little hope for them to compete directly for the attraction of fish. For this reason, the entrances should be located at those points where migrating fish will penetrate furthest upstream, or where they may be expected to congregate to rest after trying to negotiate the larger flows; the latter being based on the theory that as the fish mill about they will encounter the entrance outflow and be attracted to it.

Attraction improves with increasing discharge, so large outflows are desirable at the entrances; but once the fish have been attracted into the facilities, comparatively small flows will suffice for their ascent to the headpond. Accordingly, fish-passage facilities upstream from the entrances can be designed for the minimum flow requirement if additional water is introduced into the entrance to improve attraction. This auxiliary water can be piped from the forebay, or, if all available water is required for power generation, it can be pumped from the tailrace (maximum lift of only a few feet), or it can be supplied by a special turbine operating at a slightly lesser head than the main plant.

If adequate quantities of good quality water are available for fish passage, the design of the attraction facilities usually is not unduly complicated. In the case of a plant consisting of only a single generating unit, entrances to the fish facilities should be provided at each side of the tailrace channel adjacent to the downstream face of the power house; although in exceptional circumstances a single entrance may suffice. Larger plants, employing two or more units which may or may not be in operation at all times during the migration period, require additional entrances across the full width of the tailrace channel. These can be provided (as shown in Figure 1) by means of a powerhouse collection system—a device which consists essentially of a rectangular flume, located vertically above the draft tube outlets, extending across the downstream face of the powerhouse. Water supplied to the flume discharges through openings located at intervals along its downstream wall, and as fish seek alternative routes, when blocked at the draft tubes, they locate these lesser flows, enter the flume, and ascend to the fish-passage facilities.

The principles of the powerhouse collection system are not applicable at spillways because the distance to which fish can penetrate is constantly shifting with changing discharge. Nevertheless, it is possible to create good attraction at most spillways by judicious manipulation of the gates to create desirable flow patterns downstream. With heavy spills, salmon can be directed readily to entrances located at each side of the spillway by an adjustment of the gates, so that the greatest flows pass through the centre gates while the flows passing through the others become progressively smaller, tapering down to nil at the gates next to the entrances. In this way, the turbulent high-velocity zone immediately downstream from the toe assumes a shape, in plan, of a "V" with apex pointing downstream, and fish lead naturally along each leg to the entrances. Similar reasoning can be employed to create attraction during periods of low spill.

Unusual local conditions, not readily adaptable to the methods already discussed, could arise; and in those instances consideration might be given to the construction of a barrier dam some distance downstream from the development to prevent fish from ascending farther, and to divert them into collection facilities located in the abutments. Figure 2 shows the barrier dam and fishway at the Whitehorse Rapids power development. The exit channel from the powerhouse by-pass system may be seen in the left foreground, while the power dam and spillway appear in the upper right of the photograph.

Fish Passage Facilities for Adults

Once the fish have been attracted into the collection facilities there are a number of principles which may be employed to convey them to the headpond. Of these, fishways have proved to be the most popular choice for Pacific salmon.

A fishway consists essentially of a flume-like structure which connects the forebay with the tailrace by following a somewhat tortuous route to provide a usual floor slope of 1:8 to 1:20, depending upon the type of fishway, the site, and other requirements. Water, introduced at the upstream end, flows down the structure, passing over weirs, or through orifices, in partitions set at intervals along its length,

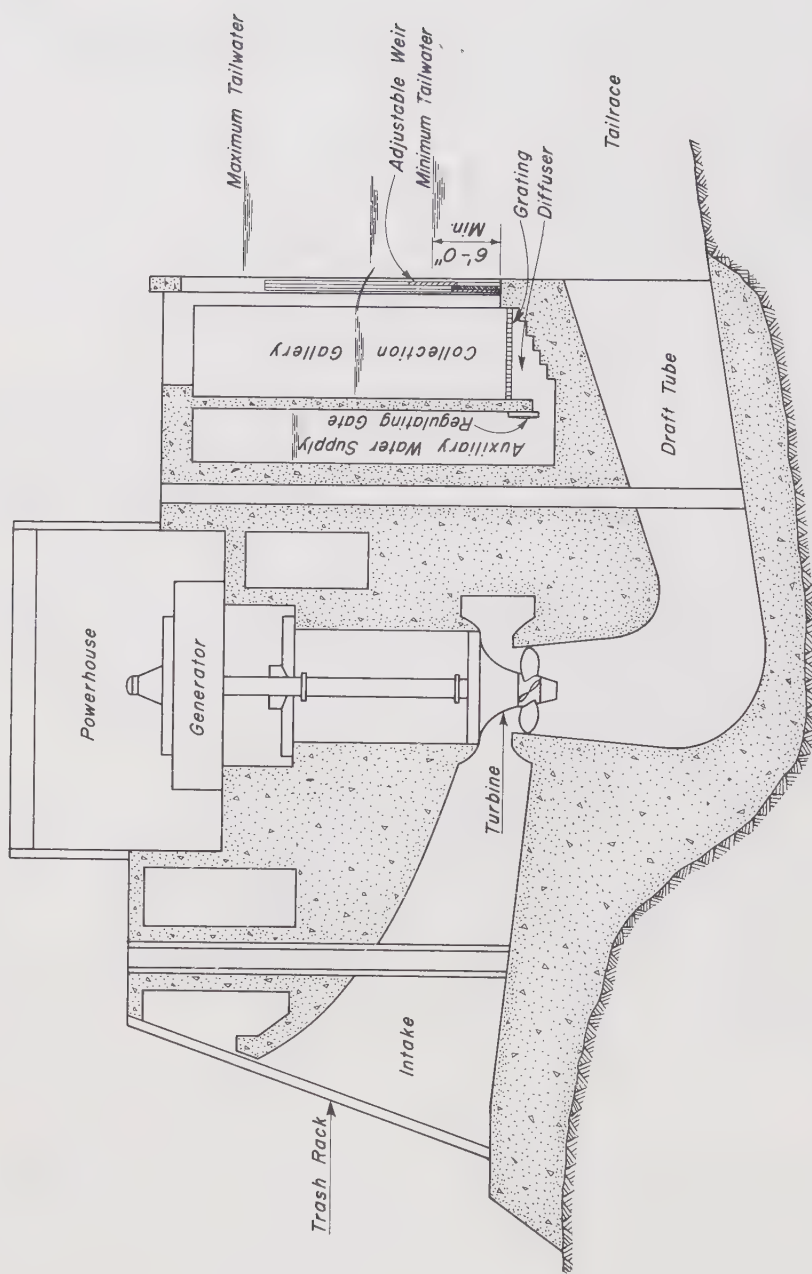


FIGURE 1. Cross section through a power-house showing a typical arrangement of a fish-collecting system.



FIGURE 2. *Fish facilities at the Whitehorse Rapids Power Development on the Yukon River near Whitehorse, Y.T.*

thus creating a sequence of step-like pools which are easily negotiated by the fish. Figure 3 shows a typical weir-type fishway at the Pelton Power development on the Deschutes River, Oregon.

The advantages of fishways are many: they allow the fish to proceed at their own pace, thus simulating natural conditions; they do not require that the fish be handled artificially, thus holding injuries to a minimum; their fish-passing ability is high in comparison with other known methods; they operate continuously; they are not dependent upon mechanical equipment which can break down at critical times;

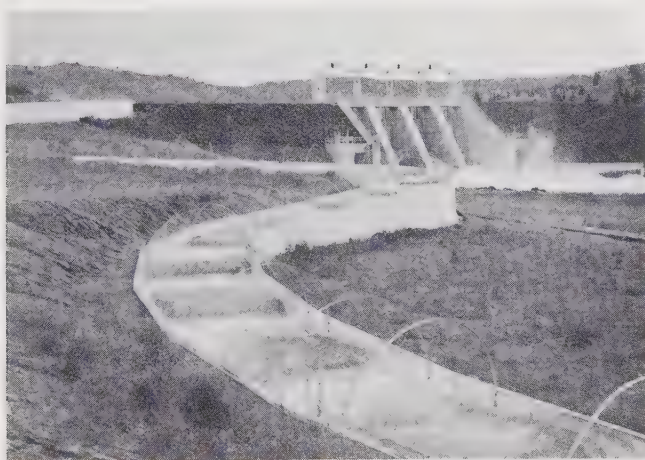


FIGURE 3. *Weir-type fishway at the Pelton Power Development on the Deschutes River, Oregon.*

their capital costs usually are reasonable when compared with alternatives; their operating costs are reasonable; and their water requirements usually are not excessive.

While fishways have no major disadvantages in so far as their effectiveness is concerned, their rambling-type layout is not readily adaptable to all sites. For instance, the problems associated with their construction in a deep, sheer-walled canyon could be so severe that they would be economically impractical. Moreover, their costs may be prohibitive at high-head developments because of the extraordinary lengths of the structures which would be required. Under these circumstances it may be necessary to resort to locks, hoists, trucks, tramways, or other comparable devices.

Fish locks (Figure 4) which operate on principles similar to those of navigation locks, are being employed with considerable success at a number of sites in the British Isles to pass Atlantic salmon around hydroelectric developments; but these runs are small when compared with many in British Columbia, and delays usually are not an important consideration. Despite this evident success with Atlantic salmon, locks are not usually as acceptable as fishways for passage of Pacific salmon for the following reasons: their cyclical operation, which involves substantial time intervals for the loading and unloading of fish, and the filling and unwatering of the lock chamber, severely restrict the numbers of fish which can be passed in a short time; they do not allow continuous passage of fish, so there is no simulation of natural conditions under which the fish proceed at their own pace; and they are vulnerable to mechanical or hydraulic breakdowns which can result in costly delays. While it might be possible to eliminate several of these shortcomings by employing a battery of locks to provide a continuous operation, the costs associated with their construction, operation, and maintenance probably would exceed those of efficient fishways.

Locks do have the advantage, however, of requiring only a small site area, and they might therefore be employed at some developments where the runs are small and fishways would be uneconomic because of space limitations.

Small runs of Pacific salmon have been transported around dams by means of mechanical devices such as tank trucks, tramways, and hoists. These, however, have all the disadvantages of fish locks, but more important, perhaps, is the fact that they require considerable unnatural handling of the fish; and this, in turn, exposes them to injuries and mortality. Furthermore, the capital costs of these devices often approach those of the more conventional methods because they not only require attraction facilities which are just as elaborate, but also they must be equipped with expensive additional works for the holding, collecting, loading, and unloading of the fish. With the exception of temporary installations, as might be required during the construction stage of a hydro development, mechanical contrivances should be considered only as a last resort.

Passage of Adults Through the Headpond

As they leave the fish facilities and enter the forebay, fish often are momentarily confused—particularly if they have been transported by mechanical means—and this lack of orientation can cause substantial numbers to be drawn

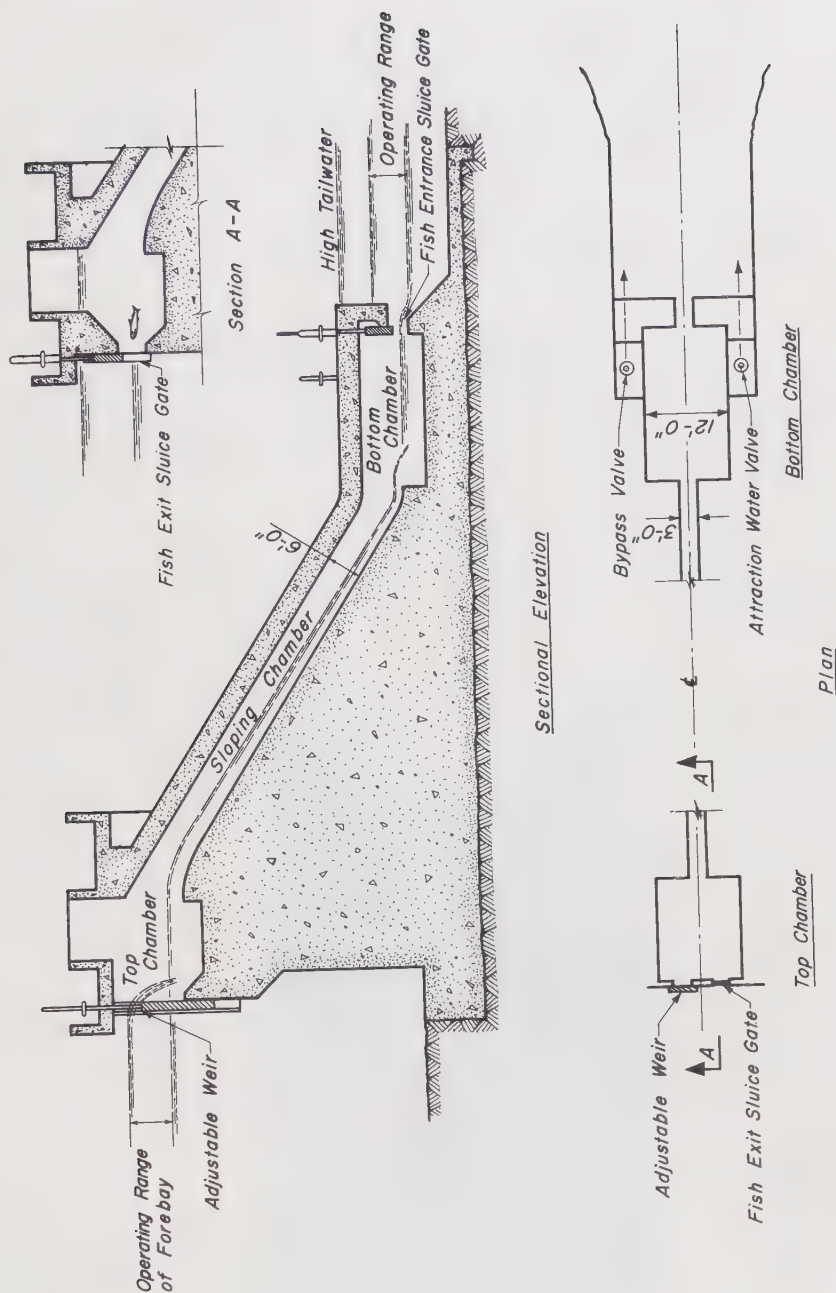


FIGURE 4. Schematic arrangement of a typical Borland-type fish lock.

into the turbine intakes or the spillways bays, from whence they are returned to the tailrace. In time, those that survive the descent undoubtedly utilize the facilities again, but the losses stemming from injuries, mortality, and delay can be a significant factor in the success of the migration. For this reason, exits from the fish facilities should be well-removed from the plant intakes and spillways.

Small impoundments created by hydro developments probably are of little consequence in so far as fish passage is concerned, but large reservoirs in which the velocity of flow is no longer perceptible to fish could cause delays because of the loss of directional guidance. Moreover, the surface layers in large reservoirs usually are warmer than normal during the period of salmon migrations, and this could result in increased rates of energy expenditure which, in the case of long reservoirs, could contribute to premature death.

Loss of Spawning Grounds by Inundation

Hydro developments can ruin spawning grounds which are situated within the backwater area by altering their hydraulic properties (depth, velocity, rate of siltation etc.) to the extent that they are no longer suitable for spawning purposes. While new spawning grounds have been constructed at a few locations to offset such losses, the principles involved must be regarded as somewhat experimental inasmuch as they have not been employed on the large scale that would be required for a major spawning population, nor have they been proved for all species of salmon. Figure 5 shows the entrance to the spawning channel constructed at Jones

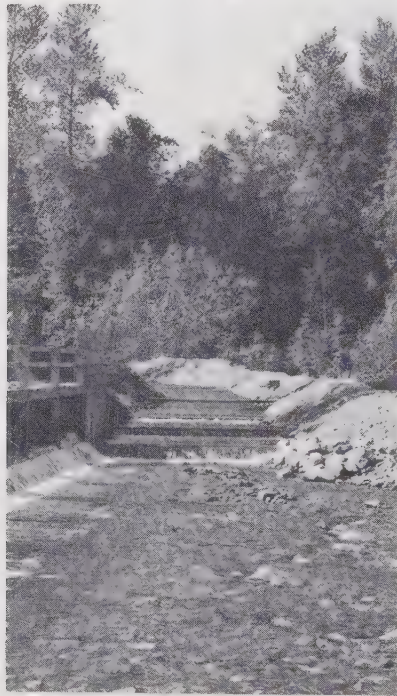


FIGURE 5. *Entrance to the Jones (Wah-leach) Creek spawning channel.*

(Wahleach) Creek, B.C. The creek flows from left to right in the photograph and the fence-like structure on the left prevents adult salmon from ascending farther and diverts them into the spawning channel.

Upstream Passage of Adults During Construction

Most hydro developments require several years to construct, and as they often obstruct fish migration long before their completion, fish-passage facilities usually are required during the construction period. While the permanent facilities sometimes can be designed to fulfill this requirement as well, changing water levels, construction schedules, and other factors often rule out such economies. In these circumstances it usually is necessary to resort to temporary facilities, and these can pose more difficult problems than the permanent solution because of construction congestion and a natural reluctance to commit funds for the construction of works which may be required for only a year or two.

Temporary fish-passage facilities usually consist of a fishway, or a trapping-and-trucking arrangement, but normal design criteria are often relaxed because of their short life expectancy.

Passage of Juveniles Through Reservoirs

The effects of large reservoirs on the passage of juvenile salmon migrating seaward are not yet fully understood, but they could be harmful because of reduced velocities, higher water temperatures, and intensified predation.

If the migrants continue to behave as they do in the natural stream and migrate downstream at approximately the rate of the river current, any reduction of normal velocities, as might result from the creation of reservoirs, would slow the rate of migration accordingly. Furthermore, it may be that river current is a major navigational aid to some species, and delays of even greater severity than those indicated by velocity reduction alone might therefore be expected, particularly in those instances when the velocity is so reduced as to be barely perceptible to the fish. Regardless of the cause, however, lengthy delays could be harmful because they may inhibit natural migrational tendencies to the extent that some fish might never go to sea, spending their entire life cycle in fresh water. This residualism, or land-locking as it is sometimes called, has been recorded with sockeye and coho salmon, and while it might occur with chinooks as well, it is not known whether or not pinks and chums would be susceptible.

The higher-than-normal water temperatures which are frequently encountered in the surface layers of reservoirs might also contribute to residualism. In this connection, the natural temperature regimes of most rivers during the seaward migrations are reasonably constant from year to year, and it could be that the migrants, on encountering the warm upper layers of a reservoir, would sound to a depth where temperatures comparable to those which existed in the natural river prevail. In these circumstances they might not find the reservoir outlets, and residualism might therefore occur.

Since reservoirs often create excellent environments for coarse fish and other species which prey on juvenile salmon, an increased survival rate among these predators could be accompanied by corresponding losses to the salmon stocks; especially if the migrants are exposed for extended periods as a result of abnormal delays.

These and possibly other effects of reservoirs created along the migration routes will be matters of some concern to fish conservationists at least until such time as the dynamics of the seaward migration are fully understood.

Fish-Passage Facilities for Juveniles

Without special provisions for their descent from the forebay to the tailrace, juvenile salmon en route to sea must pass over the spillway or through the plant, but at most hydro developments neither of these alternatives can be regarded as acceptable because of the heavy losses sustained in passage. In this connection, tests undertaken at hydro developments in the Pacific Northwest have disclosed that these losses can range up to more than 60% of the total migration. Losses of this order are, of course, intolerable, but despite intensive research in Canada and elsewhere the problems associated with the collection of juveniles in the forebay for safe passage to tailwater are still largely unsolved.

Fine-mesh screens which divert the migrants from hazardous courses to a safe bypass are, perhaps, the most obvious potential solution, but these prove to be impractical at most developments because approach velocities must be very slow to prevent impingement of the weak-swimming migrants; and this, in turn, requires an unusually large area of screen (up to 10 sq. ft. per c.f.s.). While it might be physically possible to fulfill this requirement at some sites, the capital costs of the installations which would be required for large flows would be prohibitive. Furthermore, the operating and maintenance charges would be high as a result of the problems posed by logs, ice, and debris.

Louver deflectors, which are merely variations of the screening principle, have shown in tests that they are capable of directing some species of salmon to a safe bypass, with an efficiency which approaches 100%. These devices consist of one or more arrays of vertical, flat-plate, steel bars, spaced at intervals of two to four inches, which are aligned diagonally across the flow section of a flume, canal, or other formalized structure, so that they intercept all of the flow, except for that which passes through very narrow bypass openings located at their downstream extremities. As the water passes between the individual bars, the migrants follow the line of louver array until they pass through the bypass openings into conduits which are isolated from the main flow. The migrants are thus confined to a very small portion of the total flow, so they can easily be directed to tailwater by means of pipes, flumes, trucks, or like-devices, while the bulk of the flow continues on to the development. Figure 6 shows a V-type louver arrangement, with centre dividing wall, in the Department's test flume at Robertson Creek, Vancouver Island. The bypass appears in the foreground. The louver bars are located on the inside of the legs of the "V", while flow-straightening plates may be seen on the outside.



FIGURE 6. *A V-type louver arrangement in the Robertson Creek test flume.*

Louvers can be employed effectively in specific situations, but they cannot be regarded as the complete solution because they have not been proved for all species; nor are they readily adaptable to all types of hydro developments; and they might be uneconomic for large flows. On the other hand, by comparison with alternative screens, louvers are considerably less expensive to construct, operate, and maintain; and they are at least as efficient.

Research has not been confined solely to the concept of diversion structures, however, as, in fact, virtually every conceivable principle, including the use of light, sound, odour, air bubbles, electrical fields, and numerous mechanical contrivances has been investigated. While some of these have been promising in the experimental stage, all have had operational or economic shortcomings which made them unsuitable for practical application, except, perhaps, under highly specialized conditions.

The basic problem has also been approached from the standpoint that commonly accepted hydroelectric design practices might be modified to produce conditions which would allow the migrants to pass safely through the plants and spillways. In this connection, losses at spillways are caused by abrasion and impact; and field tests have disclosed that spillways of the ski-jump type, which discharge into the atmosphere and thence into a deep cushioning pool, can be less harmful than spillways of conventional design.

While the importance of the losses which occur at spillways should not be underrated, those at the plant are of more immediate significance in British Columbia because many hydro developments would not be spilling during the seaward migrations. This does not provide any comfort, however, since, under these circumstances, the migrants would be denied a surface outlet; and, contrary to their normal instincts, they would have to sound to the plant intakes to obtain egress.

The losses incurred at the plant have been attributed to negative pressures, sudden pressure changes, cavitation, and mechanical abrasion; and in so far as modifications of the plant design are concerned, one turbine manufacturer has expressed confidence that a mortality-free machine is a physical possibility. He points out however that such a unit would be extremely costly to develop. On the other hand, it has been suggested that a turbine of this type would be less efficient than conventional machines and would therefore be uneconomic from the power viewpoint. It would seem, however, that this apparent conflict of opinion will not be resolved until such time as funds are made available for a detailed study.

Effects of Altered Discharges on Juveniles

Disruption of natural flows can have a serious effect on juvenile salmon downstream of hydro developments. For instance, those that rear in these reaches could suffer severe losses if, as might be expected below diversion-type projects, abnormally low flows occurred during the normal low-flow period; and sudden curtailment of flows, such as those which occur below peaking plants, could cause resident juveniles and seaward migrants to become stranded in isolated pockets. Moreover, reduced flows could introduce temperature problems, and predation might be intensified as a result of changes in spatial relationships.

Other Problems—General

The foregoing are by no means the only fisheries problems associated with hydroelectric developments. Others, of a more specialized nature, can arise, and although it is beyond the scope of this paper to discuss them in detail, some of these should receive mention.

One such problem is the cumulative effect of a number of hydro developments in sequence along a river. These could so alter the temperature regime of the river that it would no longer be suitable for the production of salmon. Similar conclusions might also be drawn with respect to the cumulative effects of individual factors already discussed, even though these same factors may not be of particular concern at a single development.

Construction of dams at the outlets of sockeye-producing lakes can also cause serious fisheries problems. Some races of sockeye spawn along the margins of lakes, and changes in the normal water levels might render these areas unsuitable for spawning. It may be, too, that substantial changes in the normal water levels could have a serious effect on the lake's rearing potential. Moreover, some races of

sockeye spawn immediately downstream from lakes, and their young move up to rear in the lakes as soon as they hatch: in such cases the erection of a dam at the lake outlet would alienate the young fish from the lake and there is no known means by which these very weak swimmers could be safely passed around the obstruction.

Empirical studies undertaken recently by the International Pacific Salmon Fisheries Commission indicate that the rate of survival of adult sockeye salmon returning to the Fraser River may be related directly to the magnitude of the estuarial discharge at the time when these fish went to sea. If, indeed, this relationship is valid, it may be applicable to other species and other rivers as well, and in such circumstances the flow regulation effected at hydro developments could be more serious than had heretofore been realized.

Conclusion

Pacific salmon are so sensitive to changes in their natural environment that even slight abnormalities can result in heavy losses or extinction. For this reason, hydroelectric developments which divert, disrupt, or otherwise interfere with the salmon's environment can introduce problems which are rooted much deeper than the obvious one of having to provide for their passage around dams.

The continuing research which is being directed toward these problems has met with some success, but many of the known problems are still unsolved; and it may be that there are others, of a more subtle nature, which have not yet been detected.

The seemingly slow pace of this research might logically raise questions in the minds of engineers in other fields as to why it takes so long to define the problems, let alone to develop their solutions. The answers, of course, lie in the fact that the problems cannot be solved by engineering principles alone. They are fundamentally biological problems relating to a living animal, and before the engineer can come to grips with the individual problems he must have the answers to such questions as—What are the physical capabilities of the individual species and races of salmon at all stages of their life cycles? What are their tolerances to environmental changes? How will they react to specific situations? What factors precipitate their migrations? How long can they be delayed during their spawning and seaward migrations? Why do they always return to their parent streams to spawn? How do they navigate?

Until such time as these and other important questions in the field of biology are answered, the effects which individual hydro proposals could have on the salmon stocks cannot always be accurately predetermined. This is not to say, however, that the two interests are incompatible at all sites—as, indeed, experience has proved otherwise—but each project must be assessed individually to determine whether or not it will likely cause serious fisheries problems. Some will prove to be relatively harmless, provided that certain protective measures are implemented; whereas others, regardless of the nature of the protective measures, could be undertaken only at a grave risk to the salmon stocks.

Discussion

by

A. C. Cooper

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Probably one of the most significant points to be gained by engineers from Mr. Gordon's paper is the concept that a fish, be it salmon or other species, is a living animal, not an inanimate material or thing. In attempting to deal with migrating fish, many people are prone to regard them as so much "stuff" that has to be moved from one point to another at a particular project. This approach has often led to suggestions of methods which probably would work fine for coal or wood chips or even dead fish, but which are usually quite inadequate for live fish. The design of provisions for the protection of salmon at any hydroelectric project must be based on knowledge of the fish's environmental requirements and also on knowledge of the limitations of its adaptability to abnormal conditions.

Unfortunately the salmon cannot communicate its requirements to us, so these must be deduced by observation and experiment. Migrating salmon are not particularly co-operative subjects for observation. Normally they are available for only short periods each year, so that many years of study may be required to obtain even elementary knowledge of a particular characteristic. Often it is not possible to make the desired measurements on the fish in its normal environment, or in an altered environment which one wishes to study. Experimental methods often introduce secondary influences which may obscure the particular characteristic under study. It is sometimes necessary to trace the effect of a particular environmental change through the complete life cycle of the fish. Thus anywhere from two to five years may be involved in completing a single observation, possibly with different results than had been anticipated.

Mr. Gordon has mentioned that the salmon is a cold blooded animal. Because of this the growth, activity, and development of salmon are largely determined by the environment provided by the water it is in, be it river, lake or ocean. There are certain optimum environmental conditions for each phase of the salmon's life cycle, which it is believed are represented by the average natural conditions which have prevailed for hundreds of years. The salmon is adapted to these "normal" conditions and may be severely affected by abnormal situations, such as may be imposed by hydroelectric projects. On the Fraser River there are many races of sockeye salmon, each of which has adapted to the particular spawning ground it uses. These races have different energy reserves, depending on how far they have to migrate from the sea to their spawning grounds. The migrations into the river are also timed so that the fish arrive at their respective streams when water temperatures are optimum for spawning. This specialization of races is believed to be the underlying reason that attempts to transplant runs from one area to another have not met with much success.

Preservation of the sockeye and pink salmon runs in the Fraser River can only be accomplished by preserving the normal environment to which the fish is specifically adapted. Once a race is destroyed there is little likelihood that another

race can be transplanted to the same area to replace it. Substitution of production in another area by artificial means such as spawning channels is sometimes suggested as a solution to the fishery problems posed by a particular project. This procedure would not avoid the loss of production of salmon attributable to the project, however, since if surplus lake rearing capacity is available in other areas it obviously could be utilized to increase production, not just to maintain the status quo.

Mr. Gordon has indicated that in certain instances the fisheries problems posed by a particular project may be of such a nature that reasonable solutions appear evident. There are a number of examples of this type of hydroelectric installation in British Columbia. However, despite the care in planning and the best of intentions during actual operations, circumstances or emergencies invariably arise which result in harmful effects on the salmon that it was intended should be avoided. Such occurrences are not conducive to optimism about the probable long term effect of a hydroelectric project on a salmon river.

Mr. Gordon's paper has of necessity dealt very briefly with the many facets of the fisheries problems which are created by hydroelectric projects. Engineers and indeed anyone interested in pursuing this study further should refer to the excellent texts prepared by two Canadian engineers, C. H. Clay¹ and F. J. Andrew².

Discussion

by

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*G. E. Crippen Associates Ltd.,
Vancouver, B.C.*

Mr. Gordon has presented a paper of particular interest to hydroelectric engineers on the West Coast regarding problems of developing hydroelectric resources while preserving the valuable Pacific salmon stocks and migrant sports fish. Too little information of a technical nature has been presented by authorities on the subject in the past. The general coverage which Mr. Gordon presents serves as a useful introduction and over-all review of the problem.

While Mr. Gordon's paper has considerable value for the orientation of the uninitiated hydro engineer, the following questions and comments occur.

1. The conclusion of the paper suggests that a considerable amount of research is proceeding in both biological and engineering aspects. Could the author report further data and details on the type and trends of such research? Do the results of such research indicate promising solutions?

2. The author suggests successful accomplishment of fish migration at a number of hydroelectric projects. It would be valuable if he could cite a few examples of what he considers unsuccessful as well as successful installations.

¹*Design of Fishways and other Fish Facilities*, by C. H. Clay, Department of Fisheries of Canada, 1961.

²*Sockeye and Pink Salmon Production in Relation to Proposed Dams on the Fraser River System*, by F. J. Andrew and G. H. Geen, International Pacific Salmon Fisheries Commission, New Westminster, B.C., 1960.

3. It is realized that most investigation and research associated with preserving salmon and other migratory fish is being done by either federal or provincial agencies and that many of these problems involve complex biological phenomena, the understanding of which can only be improved with time. The hydroelectric engineer is often called upon, however, to assess costs associated with spawning and fish passage in order to judge the feasibility of projects. The inclusion of a bibliography on the subject pertinent to dams and power facilities might form a valuable addition to the author's paper.

4. As the author so clearly points out, one of the most serious obstacles to construction of higher head large scale power projects on major western rivers is the passage of juveniles migrating downstream. The author quite properly infers that no satisfactory economical means has yet been developed which assures an acceptable survival rate. Extended field research in this area should be encouraged so that valuable water power resources can be developed without damaging the salmon industry.

Progress reports dealing with specific problems and their solution would be a very welcome subject for further papers, particularly as the hydroelectric potential in coastal areas receives increasing study.

Author's Reply

The author is indebted to Mr. Cooper for his forthright affirmation of the problems discussed in the paper, and for his elaboration on certain of these problems in the light of his wide experience. His warning that salmon are not just so much "stuff" is particularly noteworthy, as it has been the author's experience that the uninitiated tend to overlook, or at least to underrate, the fact that salmon are living animals whose behaviour under a specific set of circumstances is often difficult, if not impossible to predict.

Mr. Libby raises several penetrating questions to which the author will reply in the order in which they were brought forward in his discussion.

1. In the author's view it is impossible to define briefly the type and trends of current research into the fish-power question. In the Pacific Northwest alone there are at least a dozen agencies which undertake fisheries research programs, and while there is a free exchange of data between them, each agency, of necessity, must direct its program toward the development of solutions to its own immediate problems. Accordingly, the research is extremely diversified. In an attempt to be more specific, however, I would cite the following representative studies which are currently receiving attention: determination of the effects of large and small impoundments on the passage of juvenile salmon; variations in mortality and injury to juvenile salmon passing through hydro plants as related to turbine characteristics and operating conditions; the feasibility of using steeper, shorter (and more economic) fishways for passage of adult salmon; determination of the minimum flow requirements of salmon during the freshwater stage; delineation of the navigational capabilities of seaward migrants; and the relative effectiveness of

spawning channels as supplements to, or replacements for, natural spawning areas. Extensive physiological studies looking to the development of a better understanding of the animal and its tolerances are also being undertaken. Not to be overlooked either is the wealth of new information which is constantly coming available from fisheries projects which are not directly associated with research into the fish-power problem. For example, fisheries development projects which look to the improvement of salmon production through control of water temperature and discharge have been initiated recently in British Columbia; and it is expected that these, in time, will furnish much valuable basic data which will be of substantial value in assessing such problems as those posed by hydro developments.

As to whether or not the results of these research programs appear promising, the author doubts that anyone is really in a position to give a definite answer. As the paper endeavours to point out, there are no "pat" solutions to these problems, and each project must be weighed individually. It is doubtful, therefore, if it will ever be possible to state without qualification that the problems have been solved. In the author's view, however, it is encouraging to note that the fisheries authorities are in a very much better position today to answer specific problems posed by hydro projects than they were 10, or even five years ago.

2. Mr. Libby's request for examples of unsuccessful fisheries installations at hydro developments cannot be answered without some definite understanding of the meaning of the words "successful" and "unsuccessful" as they apply in this instance. In the author's experience, fish facilities at hydro projects do no more than maintain the salmon stocks at reduced levels of abundance; and he is not aware of a single instance in which the historic or maximum expected levels of salmon production have been attained on a hydro-producing river. In this sense, then, all fish facilities at hydro developments might be classified as unsuccessful, but this seems grossly unfair in view of the efficiencies of 70-90% which have been recorded at certain installations. A case in point might be the vast hydro complex of the lower Columbia River where upwards of \$100 million has been spent for fish facilities. Efficiencies in the order of 90% are reported for some of these individual installations, but it is doubtful that, collectively, they could be regarded as successful inasmuch as the salmon stocks of that system are now at an historic low level. In so far as outright failures are concerned the author is aware of only a few, and this is probably attributable to the fact that the costs of fisheries installations at hydro developments are usually of a magnitude which precludes their construction unless there is reasonable assurance of their success. One major installation which reportedly has been unsuccessful is a multimillion dollar screening device installed in the reservoir of the Brownlee project in Idaho to divert seaward migrants away from the turbines. The author understands that this device has not lived up to expectations, and that alternative facilities now are being explored.

3. The author purposely omitted the inclusion of a bibliography as the list of references which could have been cited might well have exceeded the

length of the paper itself, and it was felt that mention of only a few might lead the reader to conclude that these were the only available references. In response to Mr. Libby's specific request, however, the author would refer him and other interested readers to the two texts cited in Mr. Cooper's discussion. These are comprehensive reviews of available fisheries knowledge, and each is well-referenced.

(4) While the author is appreciative of the spirit in which Mr. Libby advances the suggestion that extended field research into the downstream migrant problem should be encouraged, it is to be noted that implementation of this suggestion involves much more than the provision of funds and qualified personnel. Conclusive test data usually can be obtained only by means of prototype experiments with the particular species to be protected; and it is not unreasonable to presume that by the time solutions to the problems are developed (if, indeed, such is possible) the salmon stocks would have been so depleted that the protective measures developed through the test program would no longer be required. Despite such handicaps research into the problems of safely passing juvenile fish around dams is continuing as the opportunities are presented; and definite progress is being made as evidenced by the recent introduction of louvers and other comparable devices.

The Co-existence of Rainbow Trout (*Salmo gairdneri* Richardson) and Largemouth Bass (*Micropterus salmoides* Lacepede) in a Small Ontario Lake

by

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and

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Abstract

A sport fishery was maintained between 1958 and 1962 in a 41.7 acre lake by annual plantings of yearling hatchery-reared rainbow trout and the natural reproduction of introduced largemouth bass. Because of unfavourable summer limnological conditions in the hypolimnion and lower thermocline, both species were obliged to co-exist in the upper 10-15 feet of surface water. An average annual fishing pressure in 1961-62 of 155 angler-hours per surface acre harvested 5.1 trout and 5.5 bass, or 4.6 pounds of these species per surface acre. Angling success was 0.05 bass and 0.06 trout per angler-hour. Factors affecting the survival, distribution, and fishing quality of both species are discussed.

Introduction

Heart Lake is a small eutrophic water of agricultural southern Ontario located within a 247 acre multipurpose recreational area owned by the Metropolitan Toronto Conservation Authority. It provides a sport fishery for rainbow trout (*Salmo gairdneri* Richardson), largemouth bass (*Micropterus salmoides* Lacepede), and brown bullhead (*Ictalurus nebulosus* (LeSueur)).

This paper reports on a study of the relative ecology of introduced rainbow trout and largemouth bass under summer limnological conditions in a shared environment.

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Description of Heart Lake

Physiography

Heart Lake is located in Chinguacousy Township, Peel County, 16 miles north of Lake Ontario at an elevation of 824 feet above sea level at Lat. 43° 44'N, Long. 79° 47'W. It has a surface area of 41.7 acres, a maximum depth of 35 feet, and a water volume calculated at 520 acre feet. The water is supplied by groundwater and surface runoff. There is no permanent inlet or outlet.

The lake is roughly heart-shaped with a north, south, and east lobe (Figure 1). The east shore has a sand and gravel beach but elsewhere the bottom of the littoral zone is composed of fibrous peat, grading to black muck in deeper water. Boggy areas are located along the north, northeast, and southern margins of the lake. The slopes surrounding the lake are either wooded with mixed hardwoods or grassed parklands developed for recreational use.

Aquatic vegetation and submerged stumps are prevalent in the shallow north and south lobes of the lake. The dominant submergents include Sago pondweed (*Potamogeton pectinatus*), busy pondweed (*Najas flexilis*), water lily (*Nymphaea odorata* and *Nuphar advena*), and water milfoil (*Myriophyllum heterophyllum*). The common emergents are the cattail (*Typha angustifolia*), arrowhead (*Sagittaria latifolia*), and duckweed (*Lemna minor* and *Spirodela polyrrhiza*).

The Fishery

In 1957, the resident fish population was destroyed by treatment with a rotenone derivative. Fish species recovered, in order of abundance, were the creek chub (*Semotilus atromaculatus*), brown bullhead (*Ictalurus nebulosus*), pumpkinseed (*Lepomis gibbosus*), golden shiner (*Notemigonus crysoleucas*), common sucker (*Catostomus commersoni*), mud minnow (*Umbra limi*), and brook stickleback (*Eucalia inconstans*) (Johnson, 1960).

In 1958, a substantial year-class of young bullheads was present in the lake, apparently the progeny of adults surviving the reclamation. A population of the fathead minnow, *Pimephales promelas*, appeared in 1961. During May of 1958, 424 adult largemouth bass and five smallmouth bass (*Micropterus dolomieu* Lacepede) were planted in the lake. In spite of a high mortality subsequent to planting, the survival of largemouth bass was adequate to establish a naturally-reproducing population of the species.

Spring plantings of hatchery-reared yearling rainbow trout of Normandale stock were made in 1958, 1959, 1960, and 1961. Stocking data since reclamation of the lake in 1957 are given in Table I.

Angling regulations as defined by the Special Fisheries Regulations for Ontario were enforced. The open fishing season for rainbow trout extended from about May 1st to September 15th, that for the largemouth bass from July 1st to October 15th. Daily creel limits restricted the catch to 5 trout and 6 bass. There was no minimum length limit on either species. Local park rules provided for angling only during daylight hours and prohibited the use of live bait in the lake. Fishing was done either from the shore or from row boats rented to anglers by the Authority.

Methods

Limnological measurements of water temperature, dissolved oxygen, carbon dioxide, alkalinity, pH, and ammonia nitrogen were made according to Standard Methods for the Examination of Water and Sewage (1955). Vertical series determinations were made weekly at a representative mid-lake station (Figure 1).

A creel census conducted during the open fishing seasons for trout and bass provided information on movement, distribution, and harvest of these species. The census of boat anglers was complete because all boats were rented from one outlet. The census of shore fishermen was done according to a sampling schedule which provided a reliable estimate of actual fish harvests. Trap nets and seines were employed to supplement data provided by the creel census. Studies on age, growth, and feeding habits were made on fish captured by all methods.

Limnology

Temperature

Heart Lake exhibited a typical summer thermal stratification. The thermocline formed in the third week of May in both 1960 and 1961, the lake again becoming homothermous early in October. The lower level of the thermocline remained relatively stable at approximately the 25 foot depth while the upper limit varied between 18 and 4 feet. Vertical temperature data taken at monthly intervals during the periods of thermal stratification are given in Table II.

Average monthly surface water temperatures for 1960 and 1961, taken one foot below the surface, are presented in Table III from which the close similarity between the two years is evident. While epilimnion waters warmed appreciably each summer, the temperature of the thin hypolimnion (Table II) remained relatively cold.

Dissolved Oxygen

Summer dissolved oxygen levels for 1960 and 1961 are shown in Table IV. A stratification of dissolved oxygen levels was apparent shortly after the formation of the thermocline in May of each year. By late May, oxygen levels at depths below about 20 feet had already become critical for fish survival. By late June, dissolved oxygen levels below 20 feet had become negligible and only waters above the 10-15 foot depth were liberally supplied with dissolved oxygen. This marked dissolved oxygen stratification persisted through July, August, and September with supersaturation occurring occasionally in the surface waters. With the autumn turnover, dissolved oxygen levels approached saturation and became more-or-less uniform throughout the water column.

Carbon Dioxide

Free CO₂ was present at comparatively low levels in the upper epilimnion immediately following formation of the thermocline in late May (Table IV) but, during June and July CO₂ could not be detected above a depth of about 10 feet. The level rose slightly in August to a maximum of only 6.6 p.p.m. at the 10 foot depth.



FIGURE 1. Aerial photograph of Heart Lake showing depth contours in feet. (A-E: location of experimental nets; —: major limnological station.) Photo by University of Illinois, Urbana, Champaign, Illinois, 1964.

Significantly higher CO₂ levels were apparent below the 10-15 foot depth by late May. Levels within the thermocline and epilimnion increased progressively during the next four months reaching a recorded high of 49.5 p.p.m. at the 25-30 foot depth in late September of 1961. Data for late October, 1960, at the time of the autumn overturn showed a major reduction of CO₂ in the deeper waters.

pH

Following establishment of thermal stratification in late May, the water was slightly basic ranging from approximate neutrality in the lower hypolimnion to 7.5-7.8 in surface waters. In 1960, there was an increase in the pH of the upper 10 feet of water to 9.6 during June and July, returning to 7.8 in August, while that of the hypolimnion remained relatively constant. In 1961, the slight stratification in pH which was evident in late May remained more-or-less unchanged during the summer months.

Ammonia Nitrogen

The level of NH₃ was relatively uniform through the water column in late May of both years at 0.14 to 0.30 p.p.m., except for the bottom waters (25-30 ft. depth) where the levels were higher at 0.46 to 2.00 p.p.m. Levels at the surface (one ft. depth) increased slightly during the summer reaching a high of 0.96 p.p.m. in 1960 but only 0.32 p.p.m. in 1961. Average NH₃ levels in the epilimnion during 1960 increased generally to over 1.0 p.p.m. in August, some threefold higher than those recorded in 1961.

Levels of NH₃ in the thermocline and upper hypolimnion increased progressively through the summer in both 1960 and 1961 and exceeded 6.0 p.p.m. in bottom waters during August of both years. During the autumn overturn of 1960, the NH₃ level was reduced approximately to that of the previous May.

Fishery Statistics

Harvest Data

Harvest data for the rainbow trout and largemouth bass are summarized in Table V. The statistics given for 1958, 1959, and 1962 are based on harvest estimates made by the staff of the Conservation Authority and are included for purposes of comparison.

Angling in 1958 recovered only three of the 424 parent largemouth bass stocked in late May of that year. This low return would seem to be explained by low availability of the species resulting from the high post-planting mortality. Initial recoveries by angling of yearling rainbow trout planted in mid June occurred in early September. An estimated 1300 anglers fished some 1,700 hours in 1958 with insignificant catches per unit effort (Johnson, 1960).

Angling in 1959 improved remarkably with some 5,000 fishermen harvesting about 1000 trout and 750 bass by an estimated 18,000 hours of angling. The trout harvest represented a recovery of 37% of the initial planting of the previous year. The bass caught, averaging about 8 inches in length, were the progeny of the parent bass planted in 1958.

During the two-year study period (1960-61) a total of 428 trout and 456 bass were taken, representing an average annual combined harvest of 4.5 pounds per surface acre. Of this catch, 45.5% of the trout and 28.0% of the bass were caught from rented boats, the remainder by shore fishermen. During 1960, 4447 anglers fished a total of 7,531 hours. This angling pressure of 180.6 angler-hours per surface acre harvested 156 trout and 256 bass. The trout harvest was 3.7 fish or 1.5 pounds per surface acre; that of bass was 6.1 fish or 1.9 pounds per surface acre. During 1961, 5,398 hours of angling by 3465 fishermen (127.6 angler-hours per acre) removed 272 trout and 200 bass, representing a harvest of 6.5 trout (3.3 pounds) and 4.8 bass (2.4 pounds) per surface acre. In 1962, the harvest of fish estimated by the Conservation Authority was similar to that of 1961 at 12.0 fish per acre and 0.07 fish per angler-hour. The seasonal trend of the combined 1960-61 harvests is shown in Figure 2.

Fishing Quality

Catch per unit effort data are given in Table V. Fishing in 1960 provided 0.05 fish of the combined species per angler-hour and, in 1961, 0.07 fish per angler-hour. Bass catches per angler-hour averaged 0.03 fish in both years; rainbow trout 0.05 fish in 1960, 0.07 fish in 1961.

Fishing quality in 1962 following the study period was approximately the same as in 1960 and 1961 proving the ability of both species to survive summer and winter environmental conditions in Heart Lake adequately to maintain angling at a sustained level.

The seasonal trend of the fishery during 1960 and 1961, using averaged data, is illustrated graphically in Figure 3. Angling pressure during May made up 35.6% of the total hours fished during the open season. It dropped to 20.2% of the total in June and remained at approximately this level through July (19.7%) and August (16.7%) at which time the season was open for both trout and bass. There was, therefore, a general decline in fishing pressure during the season, decreasing sharply in September (6.2%) and October (1.6% of the total for the season).

The total monthly catch of trout decreased steadily through the season from a high of 57.2% of the total trout catch in May to an insignificant level in September. Declining catches of trout became supplemental to the largemouth bass fishery during July and August. Some 27.2% of the total catch of bass was made in July, 63.3% in August, and 9.2% in September. Concerning the combined catch of both species on a monthly basis, optimum harvests occurred with 31.3% in May (all trout) and 31.6% in August (91% bass). During the study period rainbow trout made up 54.7% and largemouth bass 45.3% of the total combined catch of these species. During the same period an unknown but substantial harvest of bullheads was made also.

Catch per unit effort for the combined trout and bass harvest (Figure 2) ranged between 0.039 and 0.047 during the fishing season. C.U.E. was highest in August at 1.09 fish per angler-hour and lowest in October at 0.005 fish per angler-hour. The shape of the C.U.E. curve was determined solely by catches of trout in May and June, largely by harvests of bass during the remainder of the fishing season.

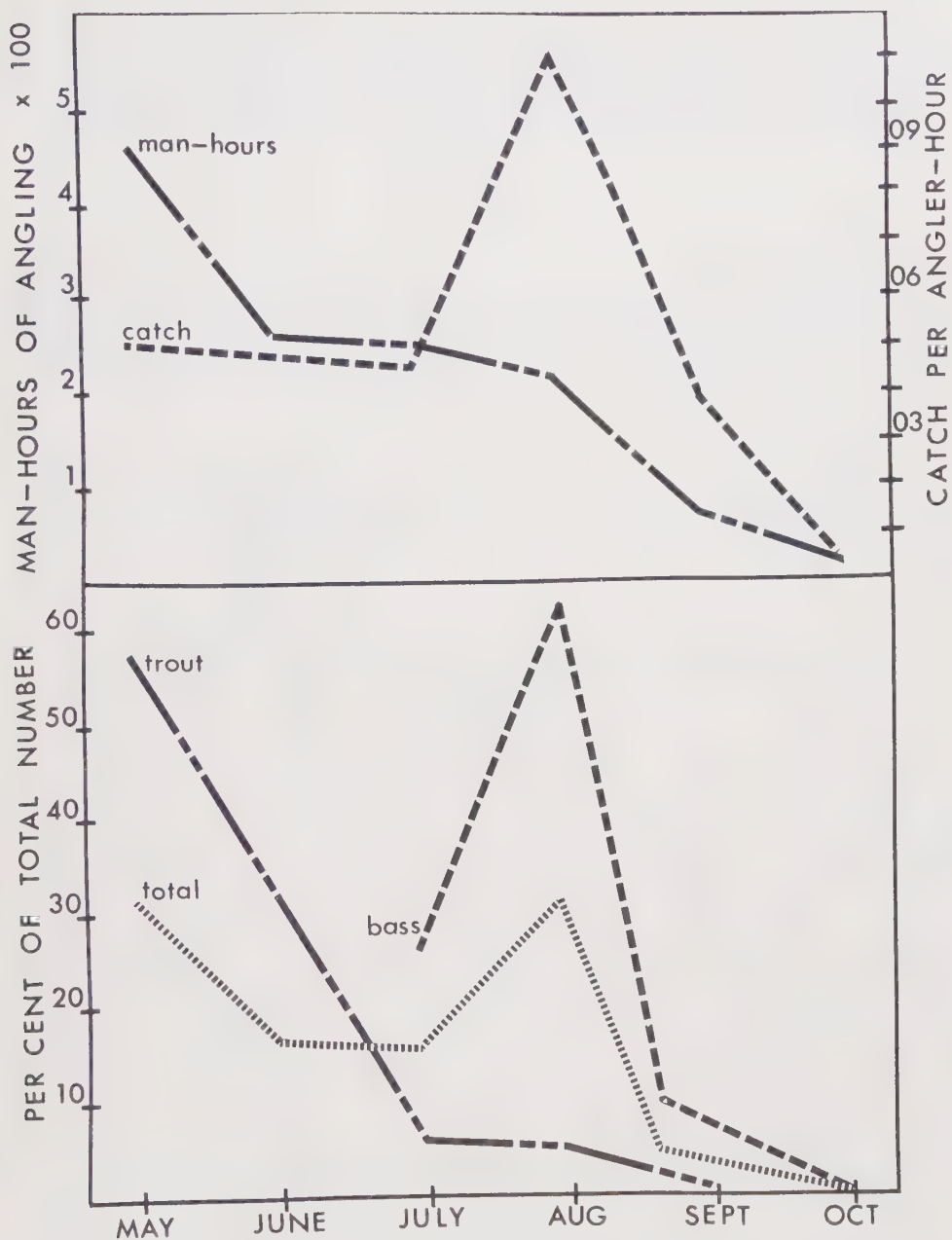


FIGURE 2. Seasonal trends in the fishery for rainbow trout and largemouth bass, 1960-61 data combined.

Biology of the Rainbow Trout

Growth

The age-length and length-weight curves for the rainbow trout based on 492 specimens taken by angling and trap-netting in 1960 and 1961 are given in Figure 3.

A comparison of the condition of the trout in 1960 and 1961 was made by the formula

$$K = \frac{W \times 10^5}{L^3}$$

The values of 1.15 and 1.16 for 1960 and 1961, respectively, show little difference between the years and indicates that the fish were in relatively good condition. Wales (1946) considered a K value of 1.00 to 1.08 to be satisfactory for rainbow trout in California.

Age Composition of Catch

Because of little overlapping in the lengths of different age groups, trout harvested by angling could be separated into year classes on the basis of length frequency (Figure 4).

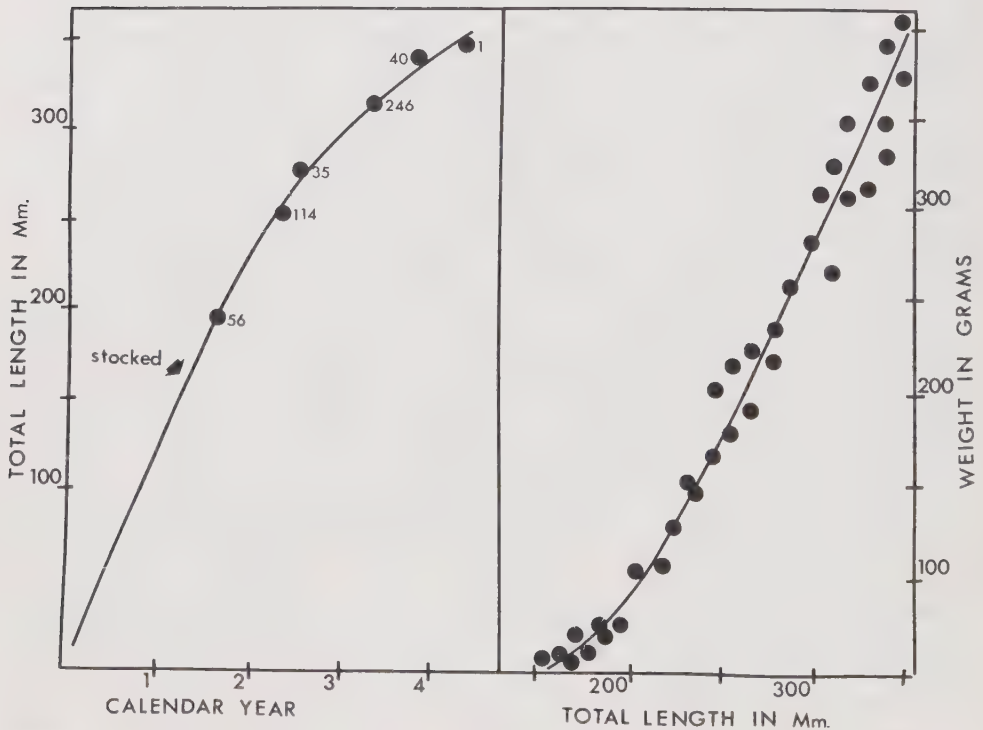


FIGURE 3. Growth curves for the rainbow trout, 1960-61 data combined.

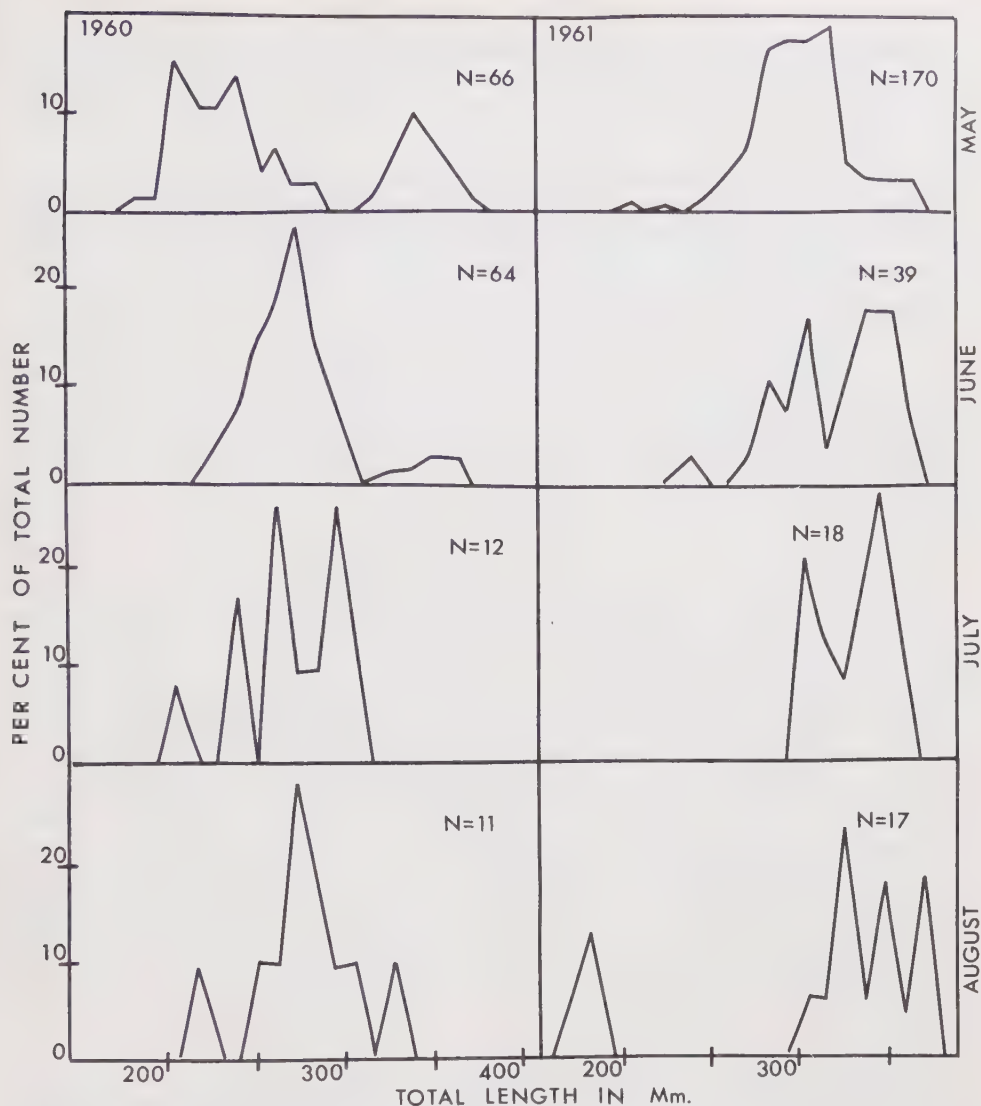


FIGURE 4. Length frequency of rainbow trout harvested by the sport fishery during the open season in 1960 and 1961.

Reference to Figure 4 shows that in 1960 the catch was composed of approximately 89% age II fish (1959 planting) and 11% age III fish (1958 planting). Fish of age I (planted in the current year) entered the fishery in September making up 8% of the August catch. Trap-netting in late August revealed the presence of numbers of trout of age I and II in the lake.

The 1961 trout fishery was dominated by fish of age III (1959 planting) which made up approximately 80% of the annual catch. Fish of age IV had virtually disappeared from the fishery and few trout of age II were taken. By August and September some fish of age I were appearing in the fishery. The presence of

numbers of year I and some year III trout in the lake in late summer was confirmed by trapnet harvests, but age II fish were scarce, indicating a poor survival of the 1960 planting.

Reproduction

No evidence of the successful natural reproduction of trout was found during the study period. Trout were observed to congregate along the beach area of the lake in early spring. Because of siltation, this shoal area would offer, at best, a marginal spawning area. Lacking, also, any tributary stream where spawning could occur, there would seem to be little likelihood of productive spawning.

An examination of the angler's catch in May, 1961, showed 24.8% of the fish harvested to be maturing fish of age III. Of these fish, 41.1% of the males but only 2.1% of the females were considered to be capable of releasing sexual products that spring. This observed age of maturity is similar to that reported by McCrimmon and Berst (1961) in Ontario farm ponds.

Seasonal Distribution

Trout were first observed each year in late April when they frequented the beach area on the eastern lobe of the lake. During early May shore fishermen were more successful than boat fishermen in catching trout. However, about mid-May there was a general disappearance of trout from the shoal areas during daylight hours and the C.U.E. of boat fishermen became higher than that of shore anglers and remained higher during the remainder of the fishing season. The improved quality of angling from boats beginning about mid-May coincided with the movement of the trout into cooler and deeper waters brought about by the warming of surface waters to 17.8°C. in 1960, and 17.2°C. in 1961.

An analysis of angling catches during late May and early June suggested a rather random distribution of trout made possible by satisfactory water temperatures and dissolved oxygen levels in most parts of the lake. However, from late June through September the trout were taken characteristically only in the lower epilimnion and the upper part of the thermocline, and rarely at a depth greater than 15 feet.

A study of summer limnological conditions (Tables II, III, and IV) in Heart Lake reveals that only a very restricted part of the lake was environmentally suitable for the survival of rainbow trout. Water temperatures approximating the preferred range for the species of 11 to 16°C. (Garside & Tait, 1958) occurred only in the waters of the hypolimnion and lower thermocline below a depth of approximately 15-20 feet during the summer months. However, by late June of both 1960 and 1961 dissolved oxygen levels at the 15 foot depth had fallen to approximately 3.0 p.p.m. and dropped off abruptly to negligible levels below that depth. Corresponding increases in free CO₂ were evident with a definite gradient being established. By late June, CO₂ levels ranged from about 14.5 p.p.m. at the 20 foot depth to 38.7 p.p.m. at the bottom. High levels of free CO₂ persisted in the hypolimnion and lower thermocline through the summer months. Ammonia nitrogen levels also increased as the summer progressed with a stratification developing from surface to bottom. NH₃ levels at the 20-30 foot depth ranged between 2.0 and 5.2 p.p.m. in July and between 2.2 and 6.6 p.p.m. in August.

From an appraisal of summer limnological conditions, it may be seen that adverse levels of dissolved oxygen, free CO₂, and ammonia nitrogen persisted in the waters of the lower thermocline and the hypolimnion through the summer months. The rainbow trout were unable to occupy the thermally suitable deeper waters of the lake, and, for survival, were forced to move into the upper waters where temperatures were marginal for their existence. Observations made on the approximate depth from which 40 rainbow trout were taken by summer angling confirmed their availability to anglers only in upper waters.

Food

The stomachs of 185 trout taken by angling were examined, of which 9 were empty. Aquatic insects (Table VI) were the dominant item in the diet, occurring in 97.2% of stomachs containing food. Diptera occurred with similar frequency (96.4%) in trout of all sizes. Although Coleoptera were found in about 20% of the young trout examined, representatives of this order were more than twice as abundant in larger trout. Entomostraca occurred in 42.6% of the stomachs, Odonata in 52.1%, and Ephemeroptera in 28.4% of the stomachs.

Fish were present in 7.7% of the stomachs containing food. No fish were found in small trout but became increasingly abundant items in larger trout, reaching a 19.5% frequency in trout over 300 mm. in length. There was no evidence that the trout ate largemouth bass or fathead minnows, but small trout and brown bullheads occurred in 2.9 and 2.4%, respectively, of their stomachs.

Algae were frequently present in trout stomachs (16.6%) through the season and in fish of all sizes. Annelida, occurring in 16.6% of the fish, consisted of leaches and common earthworms. The major source of *Lumbricus* sp. was apparently from the hooks of bait fishermen. Miscellaneous debris included small stones, artificial baits, and cigarette filters.

Biology of the Largemouth Bass

Growth

The age-length and length-weight curves for the largemouth bass based on 693 specimens taken in 1960 and 1961 are presented in Figure 5.

The average condition factor, K, for the 1958 and 1959 year-classes of largemouth bass combined (excluding young-of-the-year fish) was calculated at 1.30 and 1.43 for the 1960 and 1961 harvests, respectively. There was some variation in the K value through the summer months. All sizes of bass had a significantly higher K value ($P < 0.01$) in 1961 than 1960. From the appearance of the fish, the average K value must be considered to represent largemouth bass of good quality and, according to the standards established by Bennett (1937), would represent bass in "Average" condition.

Age Composition of Catch

The length frequency of the bass caught in 1960 and 1961 are given in Figure 6. Trap net catches in June of 1960 included two size groups of bass representing

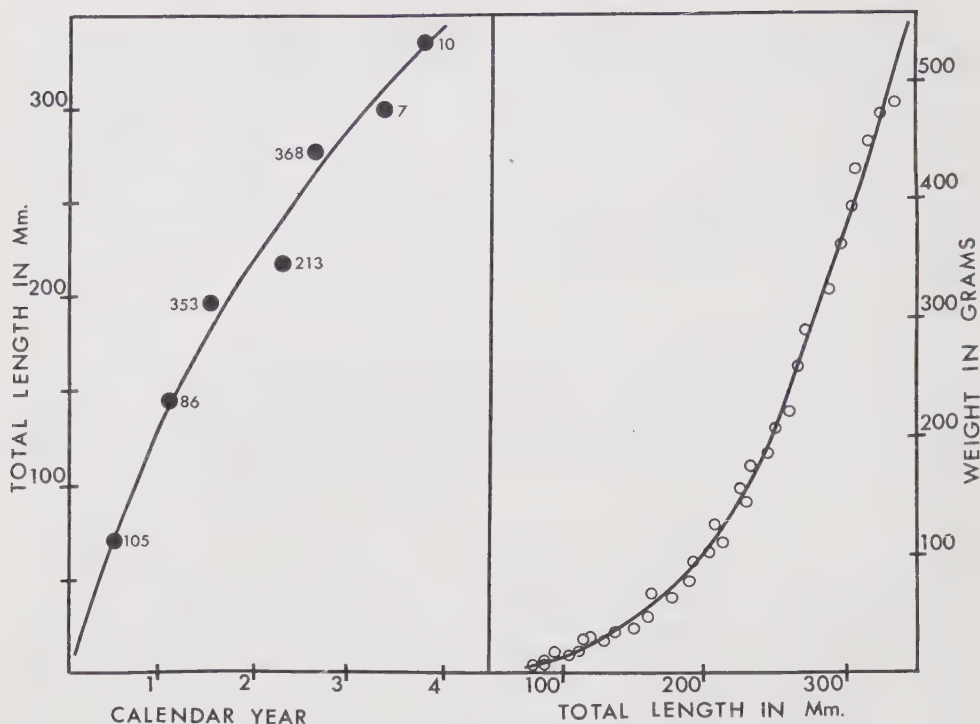


FIGURE 5. Growth curves for the largemouth bass, 1960-61 data combined.

the 1958 and 1959 year-classes. These two year-classes provided the 1960 angling harvest except for a few young-of-the-year bass which entered the fishery near the end of the summer. Bass of the 1958, 1959, and 1960 year-classes were caught by trap nets in June of 1961. The angling harvest of 1961 was composed largely of fish of ages II and comparatively few fish of ages I and III.

Reproduction

Evidence that there was some successful natural reproduction of largemouth bass in each year since the 1957 reclamation of the lake is provided by the presence of all possible year classes in the trap net catches of June, 1961 (Figure 6). Spawning occurred in late May and early June in the areas of more dense vegetation and submerged stumps in the north and south lobes of the lake. This spawning period conforms with that of Jones (1940) and Kramer & Smith (1960) that the spawning of the species begins soon after water temperatures reach 60°F (15.5° C.). A high water turbidity prevented any worthwhile observation of the actual spawning in both years but young-of-the-year bass were observed later around the shoreline.

Ripe bass were captured in trap nets only during early June of 1961. These fish were all of age III and represented the first progeny of the parent bass planted in 1958 to reach maturity.

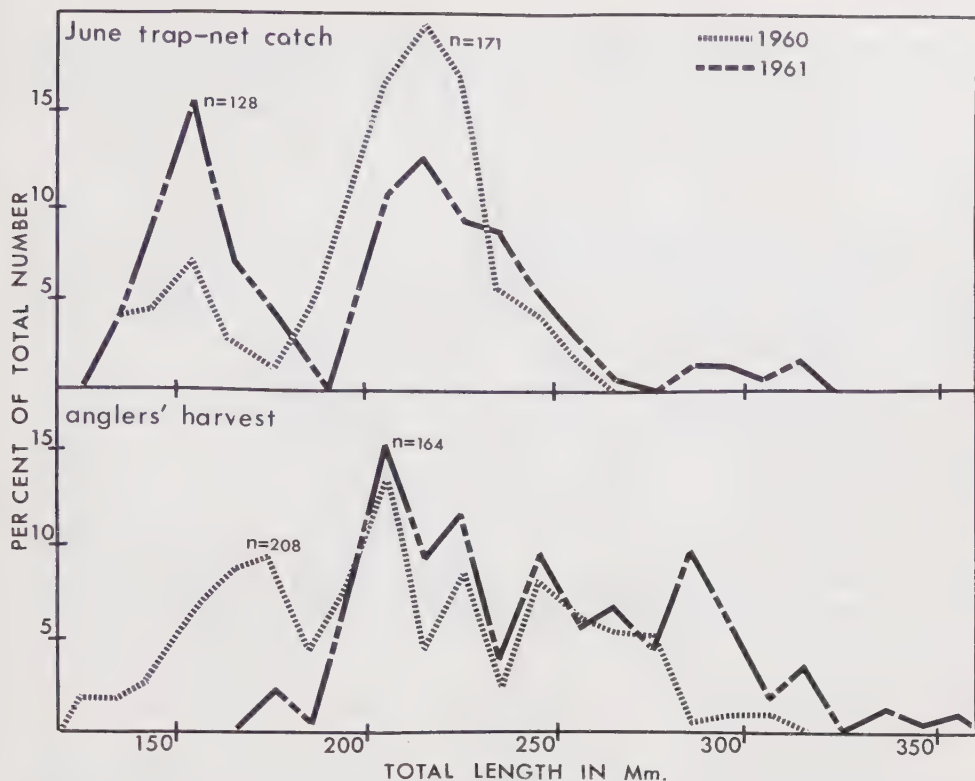


FIGURE 6. Length frequency of largemouth bass taken in June by experimental trap nets and by the sports fishery during the open season in 1960 and 1961.

Seasonal Distribution

By the time of the July 1st opening of the fishing season for bass, these fish occupied only the upper waters of the lake. The recovery of bass tagged during trap net operations suggested a random distribution within the littoral zone. An analysis of the locations of anglers' captures of 162 bass in 1960 and 1961 showed that all fish were taken in less than 15 feet of water, at temperatures between 20.0° and 26.1° C., and usually in the more heavily weeded areas. This distribution conforms with the observation of Cady *et al.* (1945), Hile and Juday (1941), and Mraz *et al.* (1961) that largemouth bass are seldom found at depths greater than the deepest water in which there is rooted vegetation.

Because of the preference of bass for warmer shallower waters, the adverse chemical conditions occurring in the lower thermocline and hypolimnion (as previously described) would seem to have had little, if any, direct influence on the summer distribution of the bass other than restricting any downward movements to beyond the 10-15 foot depth. Approximately 50% of those bass for which the depth of capture was known were taken in waters with less than 5.0 p.p.m. of dissolved oxygen and at levels as low as 0.7 p.p.m. The capture of these bass in low levels of dissolved oxygen may have resulted from their attraction to the location by the anglers' bait rather than a permanent occupation of the zone.

Decreases in dissolved oxygen levels and increases in levels of CO₂ and ammonia nitrogen which developed through the summer in the epilimnion would not seem to have influenced unfavourably the survival or growth of the largemouth bass population occupying these waters.

Food

Stomachs were collected from 225 bass taken by anglers and in experimental trap nets during 1960 and 1961 (Table VII). Of these, 115 were empty and the analysis of food preference was based on the stomach contents of 110 fish. Stomach contents from the netted bass were removed by a gastroscope similar to that described by Seaburg (1957).

Aquatic insects occurred most frequently in the stomachs of the bass. Diptera were dominant, followed in frequency by Odonata and Hemiptera, which, however, fluctuated more widely in occurrence during the season.

Fish species were the second most common item of food, occurring in 51.8% of the stomachs containing food, and in all age classes of bass present in the lake. The brown bullhead occurred most commonly followed in order by rainbow trout, fathead minnows, and young largemouth bass. An obvious increase in the utilization of the rainbow trout occurred following plantings of yearling trout in mid-June of 1961.

Discussion

The study has established that populations of rainbow trout and largemouth bass are able to co-exist in a small eutrophic lake of 41.7 acres. Because of adverse limnological conditions in the deeper waters, only that portion of the lake above the 10-15 foot depth was tenable for either species during the summer months. The fish were obligated to share the environment of the epilimnion and the upper thermocline which made available for their summer use only approximately 50% (195 acres) of the bottom area and 45% of the volume (240 acre feet) of the lake.

Harvest data for the years 1959-62 (Table V) attested to the presence of resident populations of trout and bass available for angling as a result of annual plantings of yearling trout and the natural reproduction of the bass. The initially higher harvest levels of the 1959 fishery following the 1958 reclamation would seem to have resulted from the introduction of the fish into a favourable and ecologically vacant environment. The similarity in the total number of bass and trout harvested annually between 1960 and 1962 and in fishing quality (0.05 to 0.07 fish per angler-hour) suggests the probability of a more-or-less stable fishery based on the annual plantings of hatchery-reared trout and the natural reproduction of largemouth bass.

The harvest of trout for 1960 and 1961 was lower than that occurring normally for either species in Ontario farm ponds if subjected to adequate angling pressure (McCrimmon and Berst, 1963) but above that for most larger natural waters. The level of the annual rainbow trout harvest (5.1 fish and 2.4 pounds per acre) compares favourably with that of 3.8 fish and 4 pounds per acre reported by Mueller and Rochet (1961) for a Wyoming lake. However, harvest levels reported

by Miller and Thomas (1956) for a 50 acre Alberta lake is more in line with that of the 1959 harvest (24.0 fish per acre), representing the high recovery of trout from the first planting following reclamation.

The low catch per unit effort of 0.067 fish per angler-hour (trout and bass combined) resulting from an average annual fishing pressure of 155 angler-hours per surface acre in 1960 and 1961 may be attributed, at least partially, to several causes. Firstly, angling from boats was done entirely by drift fishing since no anchors were provided with rental boats and fishermen were hard-pressed to stay in any productive fishing spot, especially if there was a breeze. Secondly, virtually all of the shore angling was concentrated in the east lobe of the lake, representing only 32% of the shoreline, because the remaining shore was more-or-less inaccessible to anglers. Thirdly, rental boats were used as well for boating and it was impossible to determine the extent of time spent in activities other than fishing. Fourthly, much of the fishing was done by inexperienced anglers who put in many hours on fishing with negligible returns. Fifthly, the angler had to contend frequently with other concurrent aquatic recreational interests, particularly during July and August, which proved to be a disturbing element to the serious angler. Consequently, the catch per unit effort resulting from active fishing was undoubtedly greater than the reported 0.067 fish per angler-hour.

Because of the common environment shared, and the fact that many fishermen did not fish specifically for any one species and, as well, kept any bass or trout caught, an accurate assessment of angler-hours spent in pursuit of either species (except during April and May) was impossible. In spite of a relatively low catch per unit effort, there was no evidence of over-fishing. As some larger trout were taken by experimental netting at the end of the fishing season in both 1960 and 1961, it is evident that a full exploitation of hatchery-reared fish was not realized, leaving a carry-over of these trout to the succeeding year. Likewise, substantial numbers of bass were taken in experimental nets near the close of the fishing season showing that anglers had not harvested all of the resident bass population in either year.

Water temperatures in the epilimnion, to which both the trout and bass were largely restricted during the summer months by low dissolved oxygen levels and other adverse limnological conditions occurring in deeper waters, had a significant influence on the growth curves. Water temperature in the epilimnion generally exceeded 20°C. from mid-June to mid-September (Table II) and was favourable for the growth of the bass.

Waters of the upper epilimnion during July and August were marginal for trout, and on occasion, surface waters exceeded the lethal temperature of approximately 25.5°C. reported for the rainbow trout acclimated to 15°C. (Bidgood, 1965) leaving only a thin stratum in the epilimnion where the trout could survive for any length of time. The trout were able to occupy water below about 15°C. until late June when diminishing levels of dissolved oxygen near the 15 foot depth forced them to move into warmer water. Consequently, their major growth was attained during April, May and early June when they could occupy water approximating their preferred temperature of 11° to 16°C. (Garside and Tait, 1958).

The co-existence of the bass and trout in a restricted environment, particularly during the summer months, allowed an opportunity for competition for food and for the development of predator-prey relationships. A study of stomach contents showed that both species fed on many of the same invertebrate food items, aquatic insects appearing the most frequently in the stomachs of both species (Tables VI and VII). In spite of a mutual use of available invertebrates, there was no evidence of a scarcity of food nor of adverse growth rates of either species.

Fish occurred in a much higher percentage of bass than trout stomachs suggesting that, during the summer months at least, they were able to make better use of available forage fish than the trout. Both species exhibited a degree of cannibalism. While no evidence was found that the trout preyed on the young bass, small trout occurred in 6.4% of the bass stomachs and very probably made up a sizable portion of the unidentified fish remains. It was apparent in 1961 that the bass were ready predators of newly-planted trout yearlings. The extent to which predation and cannibalism regulated the population levels of the bass and trout is not known although considerable numbers of fish of both species were certainly removed from the fishery by this means. However, harvest records (Table V) have shown that there was adequate escapement of young fish to maintain a relatively stable fishery for both species between 1959 and 1962.

Based on the persistence of populations of rainbow trout and largemouth bass in Heart Lake, the condition of the fish, and the sustained annual yield, it may be concluded that the two species co-existed more-or-less compatibly throughout the year. Although fishing quality was not outstanding, the fishery during the 1960-61 study period provided nearly 13,000 hours of recreational angling to some 7,900 persons, to most of whom the reward was measured in terms of aesthetic values rather than actual numbers of fish harvested. The direct annual cost of this major contribution to public recreation added only an insignificant amount to the normal operating expenses of the multipurpose Conservation Area and was recovered early in the season through gate fees and boat rentals. While more and larger rainbow trout could be made available to the fishery through modifications in the fish planting program, standing populations of largemouth bass would seem to be best controlled by natural reproduction. Whether or not improved fishing quality for rainbow trout at additional cost would be more greatly appreciated by the public, the majority of whom fish the lake as a leisurely recreational pastime, is questionable.

Table I.
Stocking data for Heart Lake, 1958-1961.

Species	Year	Age	Numbers
Smallmouth Bass.....	1958	adults	5
Largemouth Bass.....	1958	adults	424
Rainbow Trout.....	1958	yearlings	2700
	1959	yearlings	2000
	1960	yearlings	1500
	1961	yearlings	3000

Table II.

Vertical summer water temperatures taken at monthly intervals during the period of thermal stratification in 1960 and 1961.

Month	Depth (ft.)	1960 Date °C	1961 Date °C	Month	Depth	1960 Date °C	1961 Date °C
May	surface	24th 16.7	23rd 15.0	Aug.	surface	22nd 23.9	21st 21.7
	5	16.7	15.0		5	23.5	21.4
	10	15.0	14.7		10	22.2	21.1
	15	13.3	12.5		15	16.1	18.9
	20	10.6	8.9		20	10.6	13.3
	25	7.8	8.3		25	8.9	11.1
	30	7.8	7.8		30	8.3	10.6
June	surface	20th 20.0	19th 20.9	Sept.	surface	18th 17.9	27th 18.9
	5	20.6	20.6		5	17.5	18.9
	10	20.0	20.0		10	17.5	18.9
	15	15.0	15.6		15	17.0	18.3
	20	11.1	12.8		20	10.6	13.9
	25	8.3	9.4		25	8.3	11.1
	30	8.3	8.9		30	8.0	11.1
July	surface	18th 22.9	24th 25.6	Oct.	surface	20th 11.7	18th 13.9
	5	22.9	25.3		5	11.7	13.9
	10	21.1	21.7		10	11.7	13.9
	15	19.2	18.3		15	11.7	13.9
	20	11.7	13.9		20	11.7	13.9
	25	8.9	12.2		25	11.7	13.1
	30	8.3	11.4		30	11.7	11.7

Table III.

Average monthly surface water temperatures (one foot below surface) and mean air temperatures during the summers of 1960 and 1961.

Month	1960				1961			
	Mean Air Temperature (°C)	Water Temperature (°C)			Mean Air Temperature (°C)	Water Temperature (°C)		
		Min.	Max.	Mean		Min.	Max.	Mean
May	13.3	13.4	19.3	16.4	11.1	13.4	19.3	13.1
June	16.9	18.3	23.3	20.8	15.9	18.3	23.3	20.3
July	20.0	20.2	25.9	23.1	21.8	20.2	25.9	24.0
Aug.	19.1	22.1	26.1	24.1	19.2	22.1	26.1	21.8
Sept.	17.8	21.2	24.3	22.8	19.3	21.1	24.7	23.5
Oct.	—	—	—	—	12.2	19.0	20.3	17.7
Average (May-Sept.)	17.4	19.0	23.8	21.4	17.5	19.0	23.9	20.5

Table IV.

Monthly water chemistry data determined during the third week of each month, 1960 and 1961.

Month	Depth	1960						1961					
		Diss. Oxy. (ppm)	Free CO ₂ (ppm)	pH	Alkalinity		Ammonia NH ₃ (ppm)	Diss. Oxy. (ppm)	Free CO ₂ (ppm)	pH	Alkalinity		Ammonia NH ₃ (ppm)
					Phenol. (ppm)	Meth. Or. (ppm)					Phenol. (ppm)	Meth. Or. (ppm)	
May	surf.	6.6	0.6	7.5	0	81	0.20	9.4	4.7	7.8	0	140	0.14
	5	7.8	0.4	7.5	0	79	0.20	9.4	4.7	7.8	0	135	0.20
	10	4.9	0.4	7.6	0	77	0.20	9.4	4.7	7.8	0	124	0.20
	15	5.1	1.3	7.4	0	77	0.20	7.1	9.4	7.7	0	124	0.22
	20	3.8	9.0	7.2	0	84	0.30	3.6	13.3	7.2	0	124	0.30
	25	1.0	17.0	7.1	0	88	0.46	1.8	16.6	7.1	0	124	1.00
June	30	0.4	18.0	6.9	0	91	1.00	1.1	21.3	7.1	0	124	2.00
	surf.	9.4	0.0	9.6	15	91	0.24	7.5	0.0	7.8	9	121	0.14
	5	9.4	0.0	9.6	17	86	0.33	7.1	0.0	7.8	7	132	0.14
	10	9.5	0.0	9.6	13	88	0.36	6.5	0.0	7.8	7	150	0.16
	15	3.0	9.5	7.9	0	94	0.40	2.5	1.2	7.5	0	146	0.22
	20	0.0	14.5	7.1	0	95	0.41	0.1	14.7	7.2	0	137	0.26
July	25	0.0	18.8	7.1	0	97	2.69	0.2	21.3	7.1	0	162	1.60
	30	0.0	25.0	7.1	0	77	1.84	0.0	26.7	7.0	0	162	2.48
	surf.	8.6	0.0	9.6	23	87	0.24	9.4	0.0	7.8	21	75	0.24
	5	8.1	0.0	9.6	13	80	0.24	7.2	0.0	7.8	0	90	0.24
	10	3.0	0.0	9.6	5	89	0.36	—	8.7	7.7	0	125	0.76
	15	0.0	6.3	7.8	0	97	0.48	0.0	13.3	7.6	0	137	0.76
	20	0.0	15.8	6.9	0	109	4.40	0.0	20.0	7.1	0	164	2.00
	25	0.0	18.8	7.0	0	110	4.00	0.0	33.3	7.1	0	176	4.32
	30	0.0	27.1	7.0	0	117	5.20	0.0	38.7	7.1	0	183	4.80

Aug.	surf.	6.3	6.3	7.8	0	89	0.96	7.4	3.3	7.8	0	95	0.32
	5	6.3	6.3	7.8	0	84	1.04	7.2	5.3	7.8	0	105	0.36
	10	5.3	6.3	7.8	0	87	1.28	6.0	6.6	7.7	0	105	0.64
	15	0.5	12.4	7.3	0	92	1.76	0.0	16.6	7.7	0	146	1.92
	20	0.0	23.9	7.1	0	127	2.24	0.0	33.3	7.3	0	155	4.48
	25	0.0	28.1	6.9	0	123	3.20	0.0	43.3	7.1	0	164	6.56
	30	0.0	33.2	6.9	0	128	6.40	0.0	43.3	7.1	0	176	6.56
Sept.	surf.	5.0	—	—	—	—	0.52	10.4	9.9	7.7	0	120	—
	5	4.4	—	—	—	—	0.48	8.6	9.9	7.7	0	131	—
	10	6.5	—	—	—	—	0.44	6.2	9.9	7.7	0	131	—
	15	3.6	—	—	—	—	0.43	2.2	9.9	7.7	0	132	—
	20	0.8	—	—	—	—	2.88	0.0	29.7	7.1	0	176	—
	25	0.0	—	—	—	—	5.12	0.0	49.5	6.9	0	176	—
	30	0.0	—	—	—	—	5.76	0.0	49.5	6.9	0	176	—
Oct.	surf.	6.3	3.6	—	0	99	0.32	6.8	—	—	—	—	—
	5	6.4	4.2	—	0	96	0.28	6.2	—	—	—	—	—
	10	6.5	3.8	—	0	98	0.28	6.2	—	—	—	—	—
	15	6.1	2.9	—	0	96	0.24	6.2	—	—	—	—	—
	20	6.1	2.0	—	0	96	0.24	6.2	—	—	—	—	—
	25	6.5	1.4	—	0	97	0.24	4.4	—	—	—	—	—
	30	6.1	2.5	—	0	96	0.10	1.6	—	—	—	—	—

Table V.
Harvests of rainbow trout and largemouth bass from Heart Lake, 1958-1962.

Year	Number of Anglers	Hours of Angling	Total Harvest		Harvest per Surface Acre					
			Rainbow Trout		Largemouth Bass		Rainbow Trout		Largemouth Bass	
			No.	Pounds	No.	Pounds	No.	Pounds	No.	Pounds
1958*	1300	1700	15	—	3	—	0.4	—	0.07	1.1
1959*	5000	18000	1000	750	750	214	24.0	18.8	18.0	42.0
1960	4447	7531	156	61.3	256	78.1	3.7	1.5	6.1	9.8
1961	3465	5398	272	139.4	200	98.7	6.5	3.3	4.8	11.3
1962*		6501	285		221	—	6.8	—	5.2	12.0

* Harvest estimates from records of the Conservation Authority.

Table VI.

The frequency of occurrence of items in the stomachs of 169 rainbow trout containing food taken by angling in 1960 and 1961. (A=adult; L=larva; N=nymph; P=pupa)

Food Item	Percentage of Stomachs with Items	Food Item	Percentage of Stomachs with Items
Annelida.....	16.6	Diptera (L, P).....	96.4
Mollusca.....	14.8	Chironomidae (L).....	94.2
Entomostraca.....	42.6	Chironomidae (P).....	68.8
Aquatic Insecta.....	97.2	Culicidae (L).....	47.2
Ephemeroptera (N).....	28.4	Terrestrial Insecta.....	17.7
Odonata (N, A).....	52.1	Osteichthyes.....	7.7
Coenagrionidae (N).....	47.9	<i>S. gairdneri</i>	2.9
Hemiptera.....	29.6	<i>M. salmoides</i>	0.0
Corixidae.....	28.4	<i>P. promelas</i>	0.0
Coleoptera.....	50.9	<i>I. nebulosus</i>	2.4
Haliplidae.....	42.6	Fish remains.....	2.4
Algae.....	16.6	Misc. debris.....	40.8

Table VII.

The frequency of occurrence of items in the stomachs of 110 largemouth bass containing food taken by angling and trapnets during 1960 and 1961.
(A=adult; L=larva; N=nymph; P=pupa)

Food Item	Percentage of Stomachs with Items	Food Item	Percentage of Stomachs with Items
Annelida.....	3.6	Diptera (L, P).....	57.3
Mollusca.....	1.0	Chironomidae (L).....	22.8
Entomostraca.....	0.9	Chironomidae (P).....	53.6
Aquatic Insecta.....	71.8	Culicidae (L).....	0.0
Ephemeroptera (N).....	4.6	Terrestrial Insecta.....	5.4
Odonata (N, A).....	23.6	Osteichthyes.....	51.8
Coenagrionidae (N).....	9.1	<i>S. gairdneri</i>	6.4
Hemiptera.....	20.0	<i>M. salmoides</i>	1.8
Corixidae.....	13.6	<i>P. promelas</i>	4.6
Coleoptera.....	3.6	<i>I. nebulosus</i>	10.0
Haliplidae.....	0.0	Fish remains.....	34.6
Algae.....	1.8	Misc. debris.....	5.5

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The Effect of Low-level Discharge on the Summer Temperature and Oxygen Content of a Southern Ontario Reservoir

by

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Introduction

Fanshawe Lake (Figure 1), a multi-purpose reservoir, was developed in 1953 on the North Branch of the Thames River, five miles upstream from London, Ontario. It is one of 10 reservoirs constructed by Conservation Authorities on rivers in southern Ontario to provide flood control, additions to low stream flow, recreation and, in some cases, municipal and agricultural water supplies.

One of the main problems in reservoir management is the gradual enrichment or eutrophication caused by the constant addition of dissolved and suspended nutrients from the watersheds. The resulting deterioration in water quality decreases the value of reservoirs for all forms of recreation as well as for municipal water supplies.

A partial answer to the problem of eutrophication may lie in the manipulating of the discharge of water from different depths. The relationship between low level discharge and summer temperature and oxygen content was examined in the present study. The opportunity arose when the Upper Thames River Conservation Authority employed a low level discharge system to release water from Fanshawe Lake during the summer of 1963. Surface discharge was employed during the preceding 10 years of operation and limnological data were available for all years.

DESCRIPTION OF THE STUDY AREA

Fanshawe Lake is 645 acres in area at recreational lake level, which corresponds to the elevation of the crest of the spillway. The volume is 10,000 acre-feet and the maximum and average depths are 40 and 16 feet respectively. In

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addition a maximum of 20,000 acre-feet of flood water storage is available when needed. The drainage area of till plains and moraines composed of clay and loam soils is used intensively in a mixed agriculture and delivers an average discharge of 533 c.f.s. from its 560 square miles. This runoff represents approximately 11 of the 38 inches of rainfall received by the watershed annually. The fertile nature of the watershed accounts for the richness of the water in the lake (total hardness of 207 p.p.m., total phosphorus of 0.30 p.p.m., PO_4 and total nitrogen of 1.1 p.p.m. in 10 samples collected in 1963).

Water is discharged from the surface of the lake over the concrete spillway and into a stilling basin which has a volume of 640,000 cubic feet. However, between June 11 and November 14 in 1963 water was released only from a point close to the lake bottom adjacent to the dam. The flow varied from 20 to 140 c.f.s. according to the available supply in the lake. Rate of discharge and cumulative discharge are provided in Table 1.

The river below Fanshawe Lake flows in a terraced glacial spillway and is wide and shallow through most of its length towards London. Treated wastes are discharged to the river in London; therefore, the quantity and quality of water delivered to the city through the summer months are very important.

The reservoir and its tailwaters provide a fishery of approximately 7,000 man-hours of angling each year. The fish population is comprised mainly of brown bullheads (*Ictalurus nebulosus*), carp (*Cyprinus carpio*), and several centrarchids including the smallmouth bass (*Micropterus dolomieu*).

Methods

Temperature and oxygen content of the water were determined twice each month during June, July and August of 1963 at five stations on the lake and six downstream including one in the tailwaters where the effluent from the low-level-discharge tubes could be sampled (Figure 1). Determinations were made on samples from 5-foot depth intervals at all lake stations. The azide modification of the Winkler method was used to measure dissolved oxygen (American Public Health Association, 1960).

Records of water temperature in both the hypolimnion and epilimnion were available for several years previous to 1963 together with data on the concentration of oxygen throughout the lake on several occasions in mid-summer. Hence a comparison of the temperature and oxygen content of the lake during summers of surface and low-level discharge was permitted.

Observations

Temperature

Each year during the period 1953 to 1962 a thermocline persisted from mid or late June until late August or mid-September. Thermoclines were stable through much of the length of the reservoir at a depth of 15 to 25 feet. Thermal stratification was not persistent in the upstream shallow portion of the lake (Figure

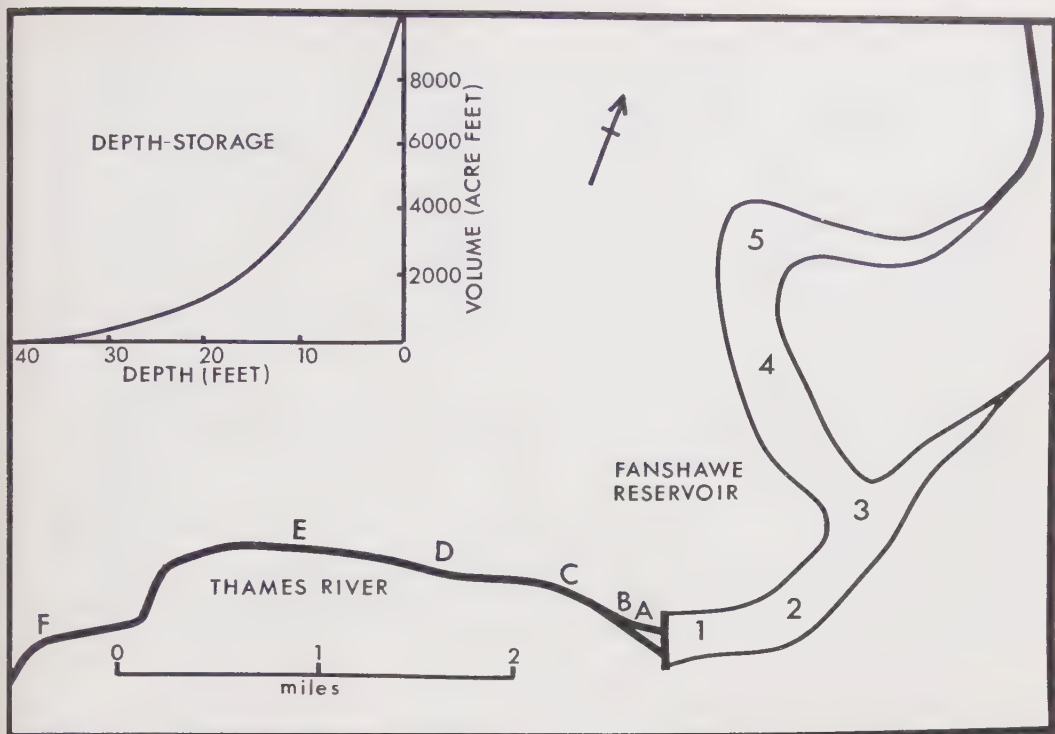


FIGURE 1. Map of Fanshawe Reservoir and tailwaters showing sampling stations. Inset graph shows storage capacity at various depths.

2). Because of the shallow, exposed character of the river above the reservoir, inflowing water was generally warmer and probably was incorporated into the epilimnion in the shallow portion of the lake. The warm surface discharge to the tailwaters remained at approximately the same temperature or was warmed slightly as it moved downstream. The hypolimnion included approximately 1,000 acre-feet or 10% of the lake volume and remained cool during the summer, between 50 and 60°F. in every year. It warmed in some years to 62 and 63°F. in September as epilimnetic waters cooled and mixed into deeper waters.

In 1963 a thermocline had been formed by June 11 and was located between 15 and 25 feet as was expected (Figure 2). The low-level discharge tubes were used exclusively after that date and by June 26, 2,300 acre-feet had been removed from

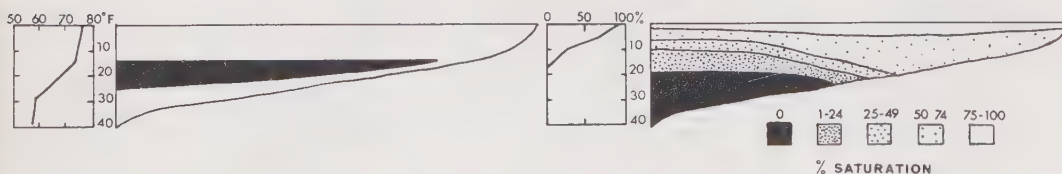


FIGURE 2. Temperature and oxygen content of Fanshawe Lake waters on August 3, 1961, which exemplify general characteristics of summer stratification during the period, 1953 to 1962 when surface release of lake waters was employed.

the reservoir, or about twice the volume of hypolimnetic water on June 11. A shallow thermocline, at 5 to 15 feet, was observed on June 26 and was assumed to be a new formation. Approximately 3,000 acre-feet of water lay beneath the thermocline. On July 9, following the release of 2,500 acre-feet after June 26, the thermocline was reduced in area and was located between 25 and 30 feet deep. It persisted at that depth through July and early August. Observations on July 23 suggested that additional thermoclines might have been formed but had been eliminated. In 1963, in sharp contrast to earlier years, the temperature of the deepest water increased through July and August, remaining greater than 60°F. and attaining a maximum of at least 66°F.

The lake was very close to being homothermous on August 28 (Figure 3). Between June 11 and August 28 approximately one lake volume, 10,000 acre-feet, had been released or ten times the hypolimnetic volume observed in earlier years and on July 11 of 1963.

The cool effluent from the lake was warmed rapidly in the tailwaters. Water temperatures in equilibrium with air temperatures were attained within 2,000 to 4,000 feet of the dam. This distance varied depending on the rate of flow (Figure 4). It is interesting to note that the effluent was warmer than the deepest water at

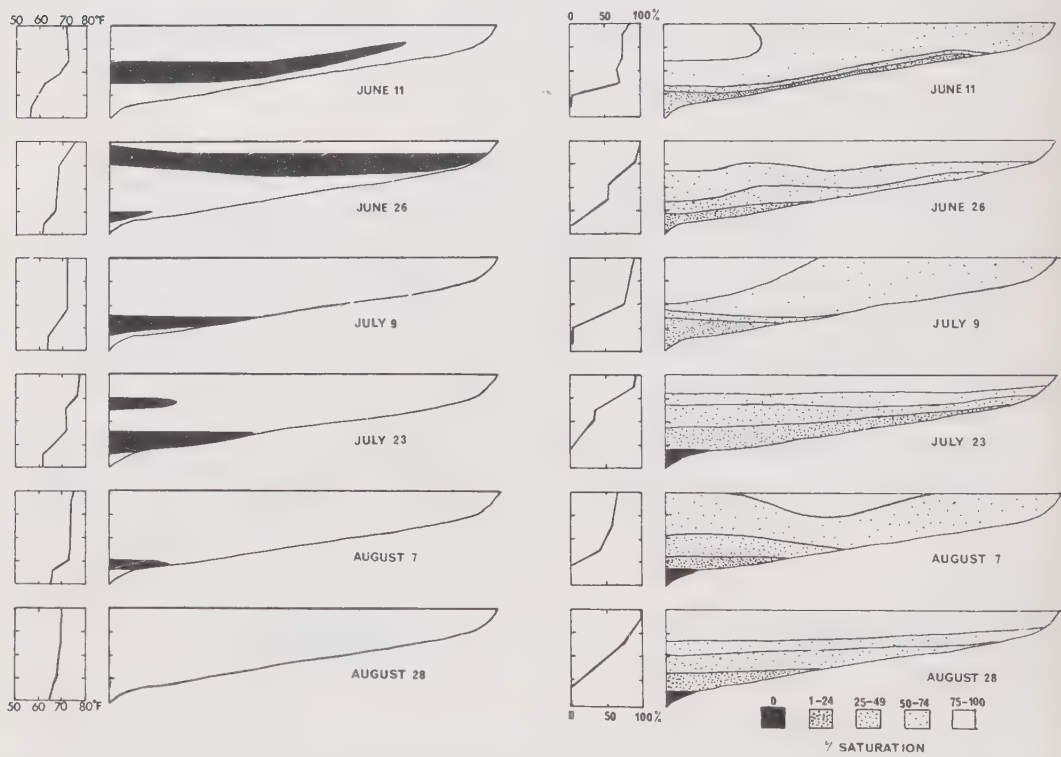


FIGURE 3. *Temperature and oxygen content of Fanshawe Lake waters as determined at intervals through the late spring and summer of 1963 when a low-level discharge system was employed.*

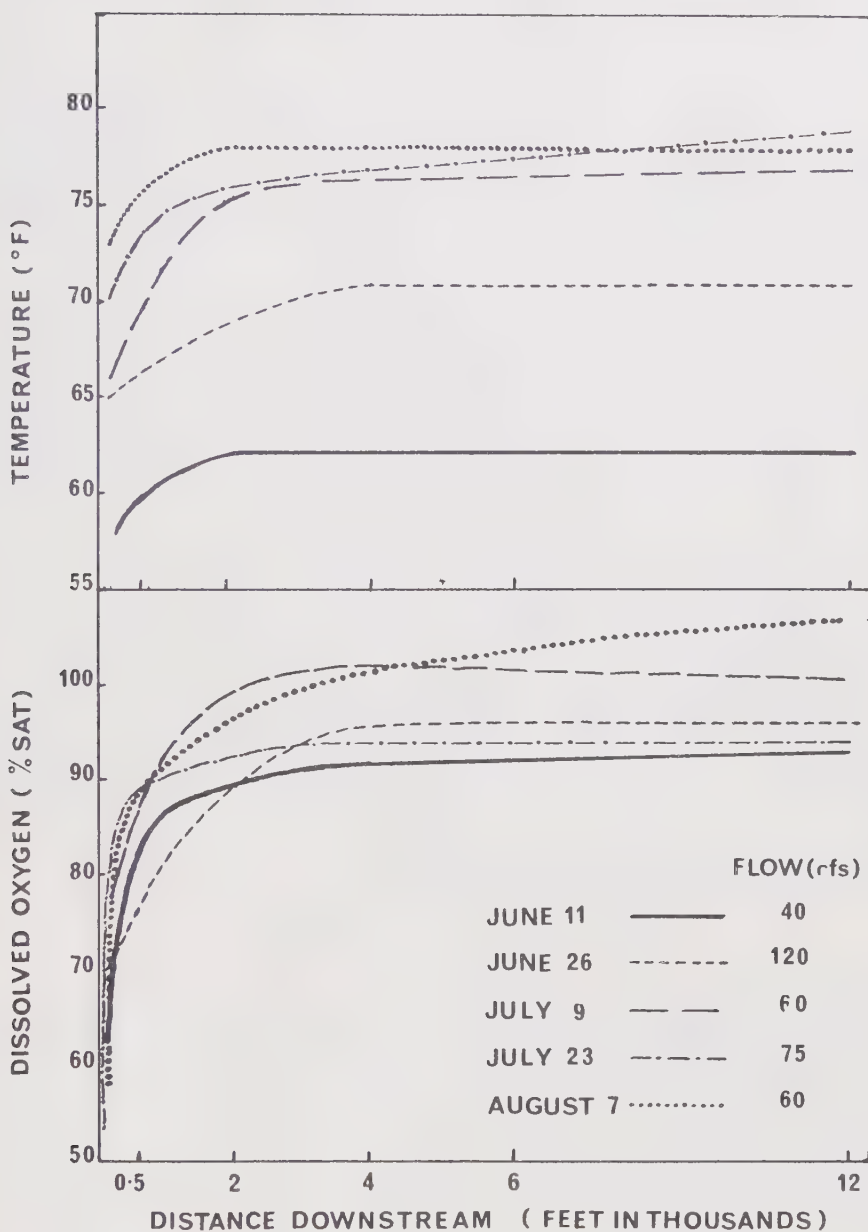


FIGURE 4. Downstream increases in temperature and concentration of oxygen in water released through low-level discharge tubes from the hypolimnion of Fanshawe Lake during the late spring and summer, 1963.

the point of release. The effluent temperature was always similar to the average temperature between the depths of 30 and 40 feet, indicating a vertical as well as horizontal replacement of water at the intake.

Oxygen content

The supply of dissolved oxygen was eliminated rapidly in the hypolimnion and lower portion of the thermocline during the summer months when surface discharge was employed. The volume of septic water which developed amounted to 1,500 acre-feet and lay deeper than 20 feet. Concentrations of oxygen of less than 50% saturation occurred through a larger volume, probably an additional volume of 3,000 acre-feet. Attempts to catch fish in trap nets set deeper than 20 feet were unsuccessful, while shallower sets yielded an abundance and variety of fish.

On June 11, 1963, the oxygen content of the hypolimnion was reduced to less than 50% of saturation but no deoxygenated volume was observed (Figure 3). Although 4,800 acre-feet of water had been released by July 9, the content of oxygen was not altered markedly through June and early July. Presumably the addition of fresh water to the hypolimnion maintained the level of dissolved oxygen at the June 11 level. However, on July 23 a small volume of septic water had formed. This volume of 75 to 100 acre-feet remained at a depth between 34 and 40 feet during the remainder of the summer. A volume of from 1,500 to 2,500 acre-feet with oxygen at less than 50% saturation was estimated. No significant change in the oxygen content of the reservoir was noted throughout the remainder of July and in August.

Oxygen concentration increased rapidly following the release of water from the reservoir, particularly at the lesser rates of discharge, 40 to 75 c.f.s. Satisfactory recovery (60 to 75% saturation) occurred in the stilling basin. On June 26 recovery was less rapid because the discharge rate was 120 c.f.s. and detention in the stilling basin only 4 hours. However, recovery appeared to be complete at a point approximately 3,500 feet downstream (Figure 4).

Discussion

The distribution of heat in Fanshawe Lake during several summers of surface discharge is compared with that during one summer when a low-level discharge was used. In the years before 1963, when the water was drawn from the surface, temperatures of 75 and 55°F. were typical of the epilimnion and hypolimnion respectively and stratification persisted from June through August. There was no appreciable rise in temperature of the hypolimnion until late summer when the surface temperature fell to 70°F. and stratification began to break down. The occasional slight rise in temperature of the hypolimnion observed during midsummer was obviously correlated with a temporary drop in the surface temperature to less than 70°F. However, in 1963, when the water was drawn from the low-level outlet, the temperature of the hypolimnial waters reached 60°F. in late June and remained between 60 and 65°F. throughout July and August. Hypolimnial water was apparently mixed with and replaced by warmer, epilimnial water that year.

During the years before 1963 a considerable proportion of the volume of Fanshawe Lake became deoxygenated (15%) and a large volume (45%) was less than one-half saturated with oxygen by mid-summer. In 1963 the oxygen content of the lake was maintained because of the breakdown in thermal stratification. Only a very small proportion of the lake (1%) was deoxygenated and only 20% was less than half saturated with oxygen.

Fanshawe Lake is characteristically eutrophic. Algal blooms have curtailed swimming periodically and the unsuitability of a significant portion of the lake for fish has been noted above. Ordinarily these conditions might be expected to become worse from one year to the next. However, as Murphy (1962) has stated, the productivity of reservoirs would be increased by the withdrawal of surface waters, containment of the richer hypolimnial water and maintenance of a shallow, well illuminated epilimnion, whereas low-level withdrawal would have the opposite effect. The regeneration of nutrients from the sediments to hypolimnial waters is widely recognized and, as might be expected, the greatest concentrations of total phosphorus, nitrogen and hardness were found in samples from the hypolimnion of Fanshawe Lake.

Acknowledgments

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Table 1.
Rate of discharge and cumulative discharge through low-level tubes from Fanshawe Lake, June 11 to August 28, 1963.

Period	Rate of discharge c.f.s.	Discharge acre-feet	Cumulative discharge acre-feet
June 11-16.....	40	480	480
17-20.....	75	600	1,080
21-23.....	140	840	1,920
24-25.....	100	400	2,320
26-July 4.....	120	2,160	4,480
July 5- 7.....	35	210	4,690
8-15.....	25	400	5,090
16-17.....	60	240	5,330
18-24.....	75	1,050	6,380
25-Aug. 14.....	60	2,400	8,780
Aug. 14-28.....	20	560	9,340

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In Memoriam

Alexander Nikolaevich Derzhavin

by

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(From *VOPROSY IKHTIOLOGII*, translated by W. E. RICKER, Fisheries
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Alexander Nikolaevich Derzhavin was the most senior member of the family of Soviet ichthyologists. He was one of the founders of Soviet ichthyology, and produced a series of searching and invaluable investigations in the fields of ichthyology, hydrobiology and fish management. More than 200 papers came from his pen, of which 155 have been published. Many of his excellent works are used in the day-to-day operations of the fishing industry.

Derzhavin was born on December 5, 1878, in Kazan, his father being a teacher. In that city he received his secondary and higher education, and there he turned to scientific work. When he had finished the Classical School, he proceeded in 1897 to the Physico-Mathematical Faculty of Kazan University, where he graduated from the Department of Natural Sciences in 1902 with a first class diploma.

At the University, Alexander Nikolaevich's scientific interests were established: he became a hydrobiologist. During the first years of his scientific activity he engaged principally in studies of water invertebrates, and only later became an ichthyologist.

His first published work goes back to his student years: he made illustrations of 12 species of Baikal amphipods, which were published in 1901. In the same year he took part in an expedition to Lake Baikal. Among the results of his studies there, he drew from nature an album in colour (about 150 illustrations) of the endemic fishes and planarians of Lake Baikal, which were published during 1907-1918 in the Reports of the expedition.

After finishing university Alexander Nikolaevich worked from 1902 to 1907 in the Cabinet of Zootomy of Kazan University, where he and the students conducted practical studies on invertebrates, histology and entomology. He drew in colour about 200 large charts for the course in Invertebrate Zoology. In the summer of 1902 he investigated the fauna of the White Sea (Onega and Kandalaksha Gulfs), and also that of the shores of the Barents Sea (the Tera coast and the Murman region) where he collected scientific material on crustaceans and fishes.

In 1908-1910 Alexander Nikolaevich took part in the Kamchatka expedition of the Russian Geographical Society. He investigated the southern part of the

Kamchatka peninsula, the basin of the Kamchatka River and the adjacent region of the sea. From the materials of this expedition he described the relict fauna of marine origin in the rivers and lakes of the Bering and Okhotsk coasts, in particular a number of new forms of mysids, amphipods, and cumaceans of the Far-Eastern Seas. For this work he was awarded the silver medal of the Russian Geographical Society.

From 1910 to 1912 Alexander Nikolaevich worked as a biologist in the Astrakhan Ichthyological Laboratory. This was the beginning of his studies on the fish fauna of the Caspian Sea, to which he later devoted a great part of his life. During these years he published a number of works on the biology and migrations in the Volga of several commercial fishes, on the food of the Caspian roach, bream and shads, and on the relict Caspian fauna in the lower reaches of the Volga. He described a new medusa from the Caspian Sea and a number of new species of cumaceans.

In 1912 on behalf of the Zoological Museum of the Academy of Sciences, Alexander Nikolaevich made an excursion along the coasts of the Black Sea and Sea of Azov. From the materials collected he revised the peracaridean fauna of the Black Sea, and also described the relict fauna of certain lakes along the Caucasian coast of that Sea.

The years 1912-1927 marked a second and longer period of work on the Caspian Sea. In 1912 he arrived in Baku as senior fisheries specialist of the Department of Agriculture, and organized the Transcaucasian Ichthyological Laboratory (later the Baku Ichthyological Laboratory, and now known as Az-NIRL—the Azerbaijan Fishery Research and Management Laboratory). He directed this laboratory for 15 years, up to the beginning of 1927.

In Baku Alexander Nikolaevich turned his hand to a wide range of scientific and practical activities. He took active part in working out problems affecting the stocks of sturgeons and salmon that support fisheries in that region, and he studied the fauna of malacostracan crustaceans and fishes. He organized continuous observations in the Kura River watershed, as well as artificial culture of osetr and sevruga sturgeons [*Acipenser güldenstädti* and *A. stellatus*] the Caspian "salmon" [*Salmo trutta caspius*] and the kutum [*Rutilus frisii kutum*]. He founded fish cultural establishments and management centres at Mingechaur, at Karadanlakh, at Bank (now the S. M. Kirov Fish Combine), in Natakhtari, and also those on the Samur and Sulak Rivers.

He developed a method for fertilizing sturgeon eggs by first washing them with water containing a certain proportion of mud, and also a method of incubating the fertilized eggs in the Seth Green apparatus. For practical purposes, this was the first time that it had been possible to rear sturgeon eggs and to begin successful artificial culture of these fish. The results of these investigations were published in a number of works, particularly in the monograph "The Sevruga" (1922).

Among the most important results of the research work done by Alexander Nikolaevich during this period, we may mention the following. He established the periodicity of the fluctuations in the stocks of shads, sturgeons and a number of cyprinid fishes of the Caspian and Black Seas, and their relation to climatic periodicity. He proposed a formula for computing the dynamics of abundance of

fish stocks. He gave an explanation of the relation between the pattern of fish migrations into the Kura River and the associated changes in wind direction. He painted a clear picture of the distribution of acipenserid fishes in the river channel at the time of their entry into the Kura, and of the speed of their ascent to the spawning grounds as related to the height of the river and the speed of its current, and to the sex and age of the fish. He investigated the marine migrations of sevriuga and osetr by tagging large numbers of these fish, the first such large-scale operation to be conducted on the Caspian Sea.

In 1914 on behalf of the Zoological Museum of the Academy of Sciences, Alexander Nikolaevich conducted faunal studies in the Sea of Azov and the lower reaches of the Don River, where he discovered and described the estuarial relict fauna.

During the revolutionary years Alexander Nikolaevich took an active part in organizing the work of Soviet institutions. In 1917 he headed the "Kaspseld" Bureau, which was engaged in the distribution of shad to the population of the Russian Republic. In 1918 he was a member of the Directorate of the Fishing Industry and a member of the Commission for Nationalization of the Fishing Industry. In 1919 he took part in founding Baku University, organized the Department of Zoology and from that time to 1923 was its first professor. From 1922 to 1926 he was Director of the Persian-Caucasus branch of the Fish Management Authority—which conducted fish-management work on the osetr sturgeon of the Sefid-Rud River and made faunistic investigations in the waters of northern Iran. In the course of this he described a number of new fishes from Iranian waters. From 1922 to 1926 he was consultant to the fisheries branch of the People's Commissariat of Agriculture of the Armenian Republic. In this Republic he organized the Sevan Hydrobiological Station and promoted the acclimatization of the Chud and Ladoga whitefishes in Lake Sevan, which species now support fisheries there.

In 1927 Alexander Nikolaevich investigated the fishing industry of the Turkmenian SSR—in the Gulf of Gasan-kuli, on the Murgab and Atrek Rivers, and on the Amudarya.

At the beginning of the 1920's Alexander Nikolaevich took part in a number of workers' committees that had to do with scientific and industry matters, which were organized by the Moscow Directorate of Fishing and the Fishing Industry. For example, in 1921 he attended the first meeting of scientific workers on fishery affairs at which there were gathered together, for the first time since the Revolution, many of the scientific workers from the various regions of our country. Those who were present at this session well remember the fascinating three-hour address that Derzhavin presented concerning the Kura sevriuga. In it he proposed a number of new questions, which he answered using a method that was entirely new in principle (a mathematical formula for determining the size of stocks, relationship of parent stocks to climatic periodicity, and so on).

In 1922, at the meeting on fish management assembled in Moscow by Glavryba, Derzhavin put forth some interesting suggestions concerning behaviour of the Caspian salmon, and also on the behaviour of acipenserid fishes in the Sefid-Rud and Sulak Rivers.

At the 1923 conference of leaders of scientific and industry organizations sponsored by Glavryba, Alexander Nikolaevich gave a report on the work of the Baku Laboratory. In it he noted that in 1917 laboratory personnel had been commandeered to process fish, while the laboratory's vessel *Shemaika* had been requisitioned. Only in 1922 had it become possible to resume the interrupted work. At first the staff of the laboratory consisted of the director and three laboratory assistants. The laboratory and apparatus had been saved and the vessel was returned. In 1922 Derzhavin's monograph "The Sevriuga" was published. From this time on the work of the laboratory began gradually to revive.

From 1927 to 1931 Alexander Nikolaevich worked in Vladivostok as director of the Pacific Fisheries Research Station, later re-named the Pacific Research Institute for Fisheries and Oceanography (TINRO). He investigated the stocks of fish in the far eastern seas, the biology of the chum salmon and the Pacific semga [*Salmo penshinensis*], the Kamchatka crab, problems of the fur seal and sea otter industries, and also studied the peracaridean fauna of the seas and fresh waters. He made expeditions to Kamchatka, Sakhalin, to the Amur and Ussuri Rivers, and along the coast of the Sea of Japan. In 1929 he organized a meeting of the fishing industry in Khabarovsk, at which he presented a report on the usable resources of the Far-Eastern seas. In 1930 he began work as Professor at the Dalrybvtuz (Far Eastern Fisheries Institute), in its Department of Commercial Invertebrates.

In 1932 Alexander Nikolaevich again returned to Baku and worked there up to the end of his life, that is, for 31 years. At first he headed up the Fish Management Section of the Caspian Fishery Institute, and in the autumn of 1932 he was named Head of the Aquatic Animals Division in the Zoological Section of the Azerbaijan Branch of the Academy of Sciences (AzFAN), which later became the Institute of Zoology of the Academy of Sciences of the Azerbaijan SSR. In 1936 he was made Associate Director of the Kura Experimental Fish-Cultural Station (KERZ), which had been constructed according to his specifications for the purpose of developing methods of culturing sturgeons. At KERZ he successfully applied a method of holding maturing sturgeons until they were ripe, under conditions approximating those of nature, this being the so-called "basin" or "ecological" method of holding the adults.

In 1937 the Commission on Advanced Degrees nominated A. N. Derzhavin to the scientific degree of Doctor of Biological Sciences without defence of a dissertation, and awarded him the title of Professor. Because of his numerous heavy duties, from 1938 onward Alexander Nikolaevich ceased his work in the Caspian Institute, and from 1940 gave up the work at KERZ, giving his whole attention to the Institute of Zoology of AzFAN. In addition, from 1944 to the end of his life he was permanent consultant for the Sevan Hydrobiological Institute of the Academy of Sciences of the Armenian SSR.

Derzhavin had profound knowledge in the fields of ichthyology and hydrobiology. His monographs on the biology of the sevriuga, on the production of stocks of acipenserid fishes and of Caspian salmon, on the mysids of the Caspian, and others, are widely known in the Soviet Union. They have great theoretical and practical importance and are used in fish management.

Professor Derzhavin believed that one of our basic needs is to develop measures for the continued production of fish stocks in these days of grandiose hydro-electric and irrigation projects in the Soviet Union. He took part in developing all of the fish-cultural measures directed at maintaining and expanding fish stocks, and the further development of the fishing industry of the southern seas of the Soviet Union.

While permanent consultant on questions of planning fish-cultural measures in connection with the construction of the Mingeaur Dam, Alexander Nikolaevich worked out the fundamental biological and fishery premises for the project. These basic premises included detailed biological characterization of objectives and functions for the construction of three sturgeon hatcheries, three salmon hatcheries, three spawning and rearing establishments, four artificial lakes, the Varvarin Fish Combine, and the Mingeaur Reservoir, etc., which have now been realized. He was continually consulted by management and industry on questions concerning fishing and fishery management. His monograph "Production of Sturgeon Stocks" deserves special attention. In it he applies the results of an analysis of a wide range of materials and experimental investigations to elaborating a system of measures for the development of the sturgeon industry.

In the monograph "Production of Caspian Salmon Stocks", in addition to the development of production methods, important theoretical questions involving the geographical and biological variability of salmon are also considered. It is also shown experimentally that it may be possible for the direct action of factors of the external environment to induce changes in the heritable properties of salmon, in directions that are commercially useful. In 1956 Alexander Nikolaevich published a comprehensive (35 printed pages) handbook of materials on the Kura fisheries ("The Kura Fishing Industry", published by AN Azerbaijan SSR) under conditions created by the Mingeaur dam, in which he outlines measures for the protection of the stocks of commercial fishes in the Kura.

In the Reports of the Institute of Zoology of the Academy of Sciences of the Azerbaijan SSR, in its periodical publications, and also in other publications of the Soviet Union, Alexander Nikolaevich has published a series of works on the problem of the Caspian fish stocks, the production of stocks of sturgeons, salmon and other fishes. In the monograph "Mysids of the Caspian Sea" he describes a new family and genera of mysids. He published the results of his studies of the fauna of subterranean arthropods of the Transcaucasian region, and the extinct arthropod fauna of the Upper Sarmatian strata of Eldar and Grozny. In the collection "The Animal World of Azerbaijan" (1951) he contributed 16 articles on the history of the fauna of the Caspian and of the fresh waters of Azerbaijan, concerning fishes, molluscs, bryozoans, crustaceans, worms, coelenterates and sponges.

Derzhavin was a regular participant in the federal conferences on fishery affairs and fish culture which took place in Moscow. His reports were always very interesting. His wide range of interests and information enabled him to conduct investigations at a consistently high level of technique and methodology, and with a broad knowledge of both Russian and foreign literature. His communications concerning fish-cultural work, and his predictions concerning the effects of regula-

tion of the Kura River and construction of Mingechaur dam, were always energetic and broadly argumentative. Almost every report by Alexander Nikolaevich was an "event" in the lives of ichthyologists.

Derzhavin did a great work in preparing highly-qualified recruits for the field of ichthyology. He was consulted by many specialists, and he guided many students not only in Azerbaijan but also in the other Republics, especially those of the Transcaucasian region.

Alexander Nikolaevich also did much editorial work in preparing for publication monographs, reports and proceedings of the Institute of Zoology of the Academy of Sciences of the Azerbaijan SSR, and also for various biological journals.

For the efforts which he had put forth in the field of hydrobiology and ichthyology and fish culture, Derzhavin in 1954 was created an Honored Worker in Science by the Azerbaijan SSR. In 1955 he was chosen an active member of the Academy of Sciences of the Azerbaijan SSR. The Presidium of the Supreme Soviet of the USSR awarded Derzhavin the Order of the Red Banner of Labour, the Badge of Honour, and medals.

Alexander Nikolaevich died on September 17, 1963, after a painful illness. Thus ended the life of a great scientist, whose energy was tireless. He continued to work almost up to the day of his death. In his later years Alexander Nikolaevich had even occupied himself with literature: he was attempting to make a translation of "Slov o polky Igoreve", giving it a new interpretation.

The image of Alexander Nikolaevich Derzhavin as a great scientist, an energetic organizer and a thoroughly humane person is preserved in the memory of all those who had the opportunity to work with him or meet him in the course of his long, many-faceted, creative career.

